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Mobilisation thresholds for coral rubble and consequences for windows of reef recovery

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Supplementary Material

Figure S1 Rubble bases used in the wave flume for (a) 'free' not interlocked rubble pieces; and (b) interlocked rubble.

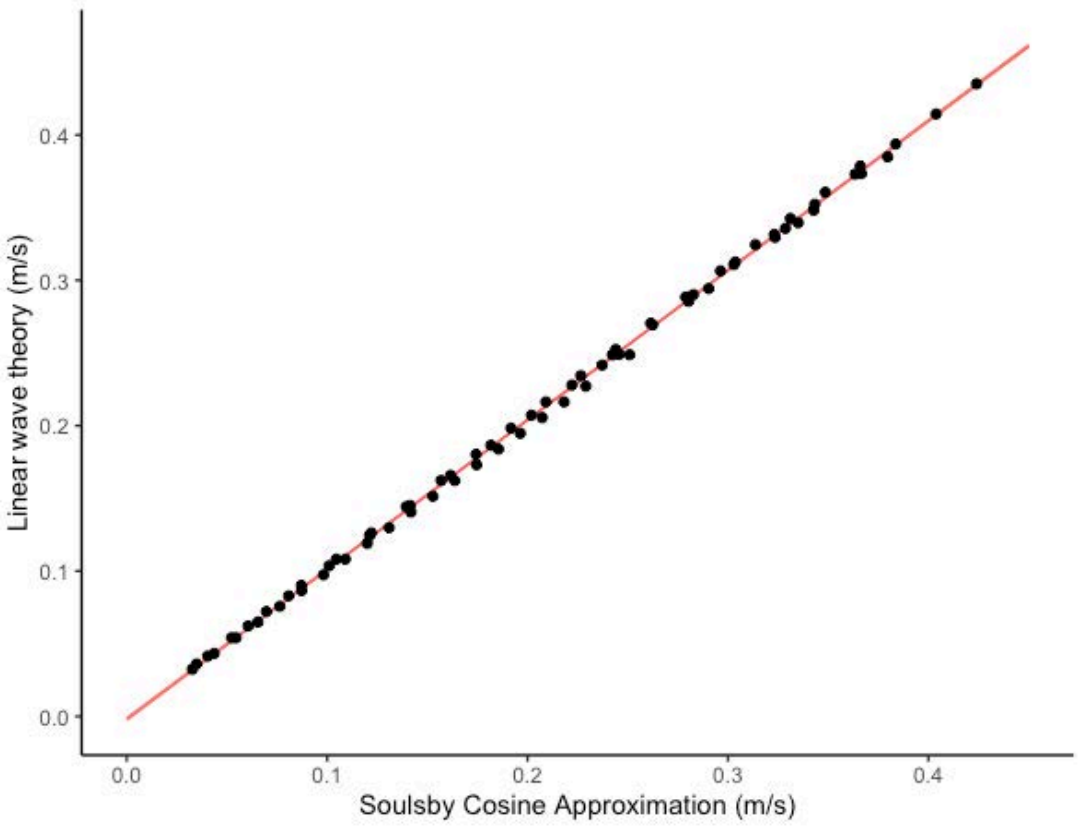

Figure S2: Relationship between the bottom orbital velocity estimated using the Soulsby Cosine Approximation (x axis) and Linear wave theory (y axis) for wave conditions used in the wave flume. Red line designates linear regression equation for relationship: $y = -0.0018 + 1.0289x$ ($R^2 = 0.999$).

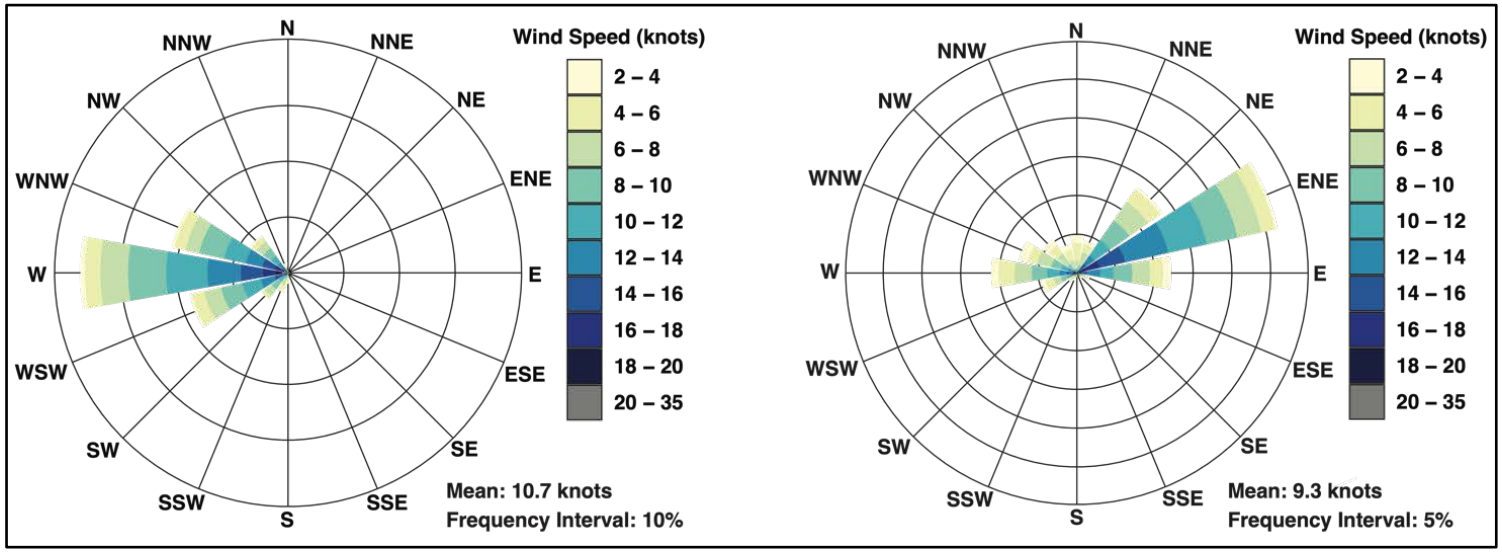

Figure S3 Windrose of mean wind speed (knots) and wind direction data measured at Hulhumale ranging 1985-2018 for western monsoon, showing monsoonal mean wind speed (left); and (right) north-eastern monsoon, showing monsoonal mean wind speed (Source: Maldives Meteorological Service, Government of Maldives).

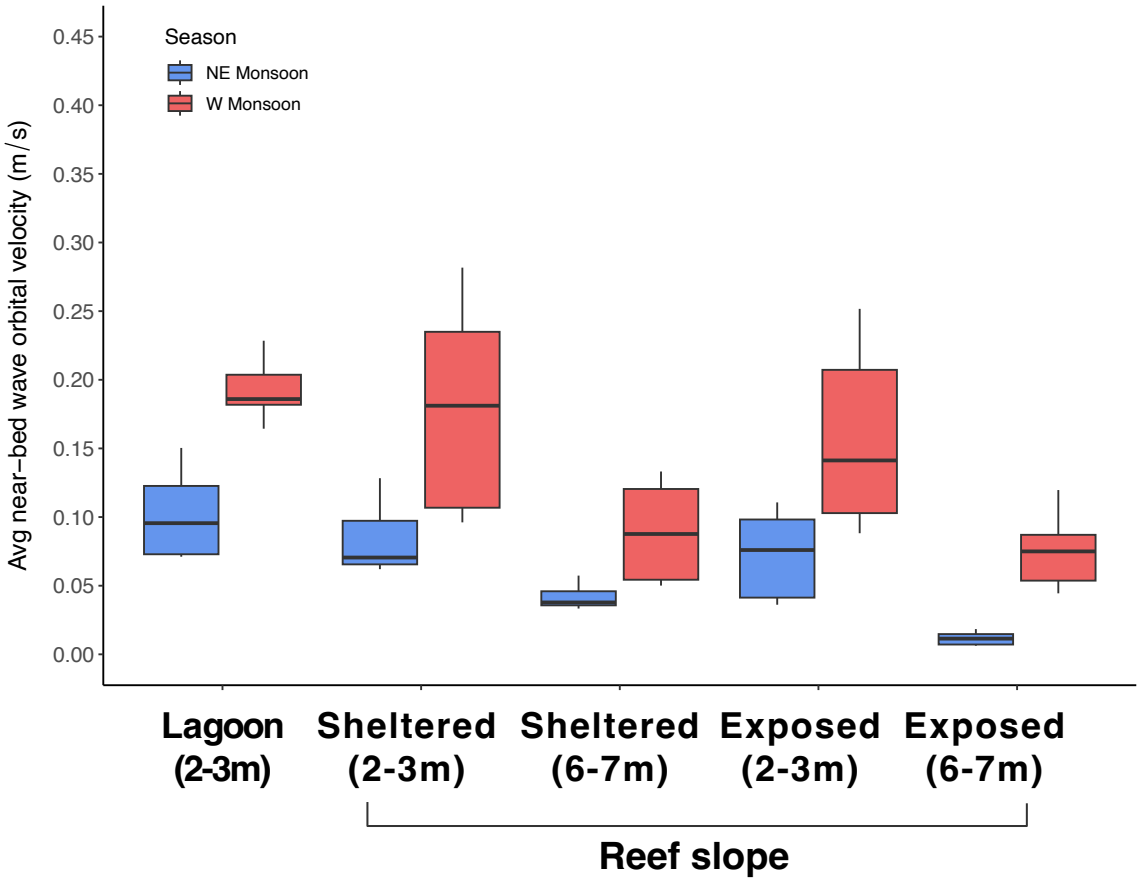

Figure S4 Boxplots representing the range of the nine (one per day for three days, across 3 sites) average peak velocity values (the average of all velocities across each day, as opposed to the fastest velocity within each day period, shown in Figure 4 of the manuscript), estimated for each habitat in each monsoonal observation period.

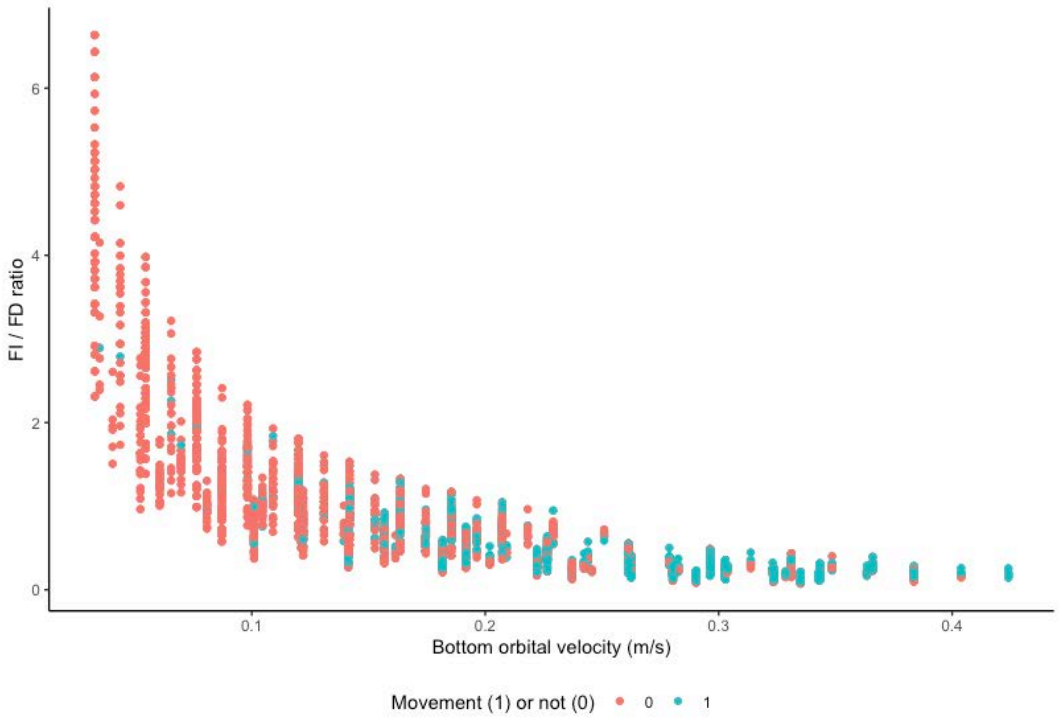

Figure S5: The relationship between bottom orbital velocity as estimated using the Soulsby Cosine Approximation and the ratio of the inertia force and drag force, FI/FD, for every individual case in the wave flume (including free and interlocked rubble pieces across multiple trials and wave conditions). Note than even when FI=FD, the contribution to the maximum total force from the inertia force is only 0.25FD. Colours indicate whether the rubble piece moved (including rocking, transport or flipping) in each case.

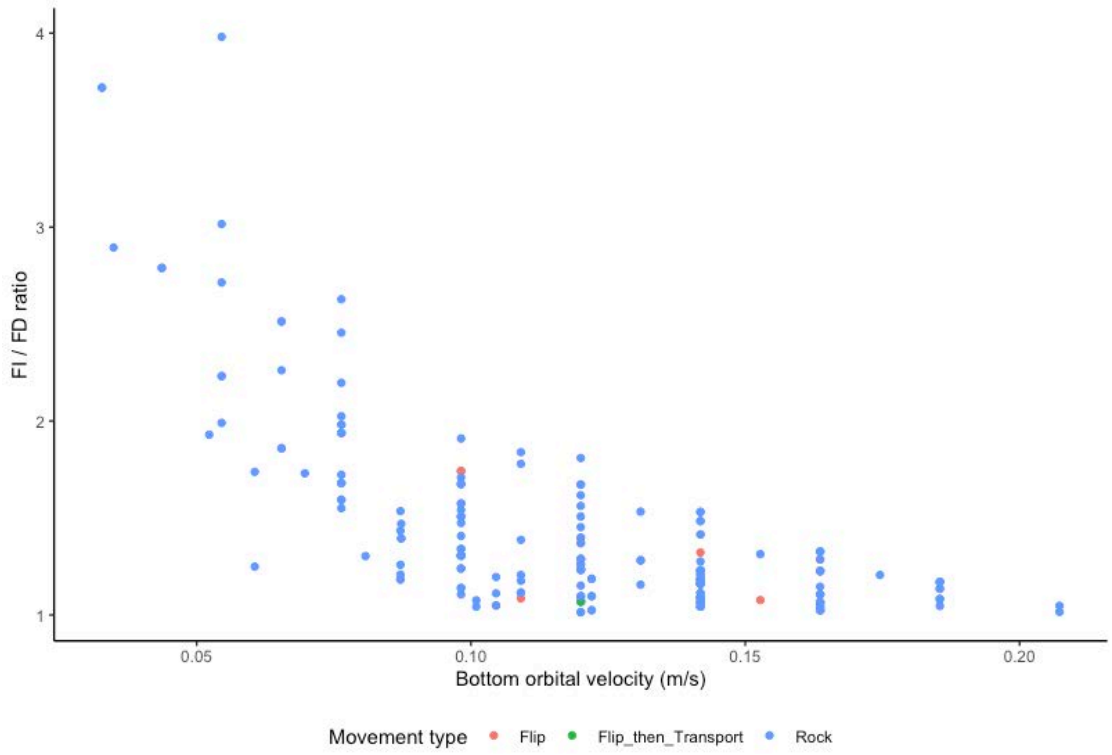

Figure S6: The relationship between bottom orbital velocity and the FI/FD (inertia to drag force) ratio for cases where a) inertia was determined to have the potential to be significant and b) rubble moved. Colours indicate the type of rubble movement (majority rocked only)

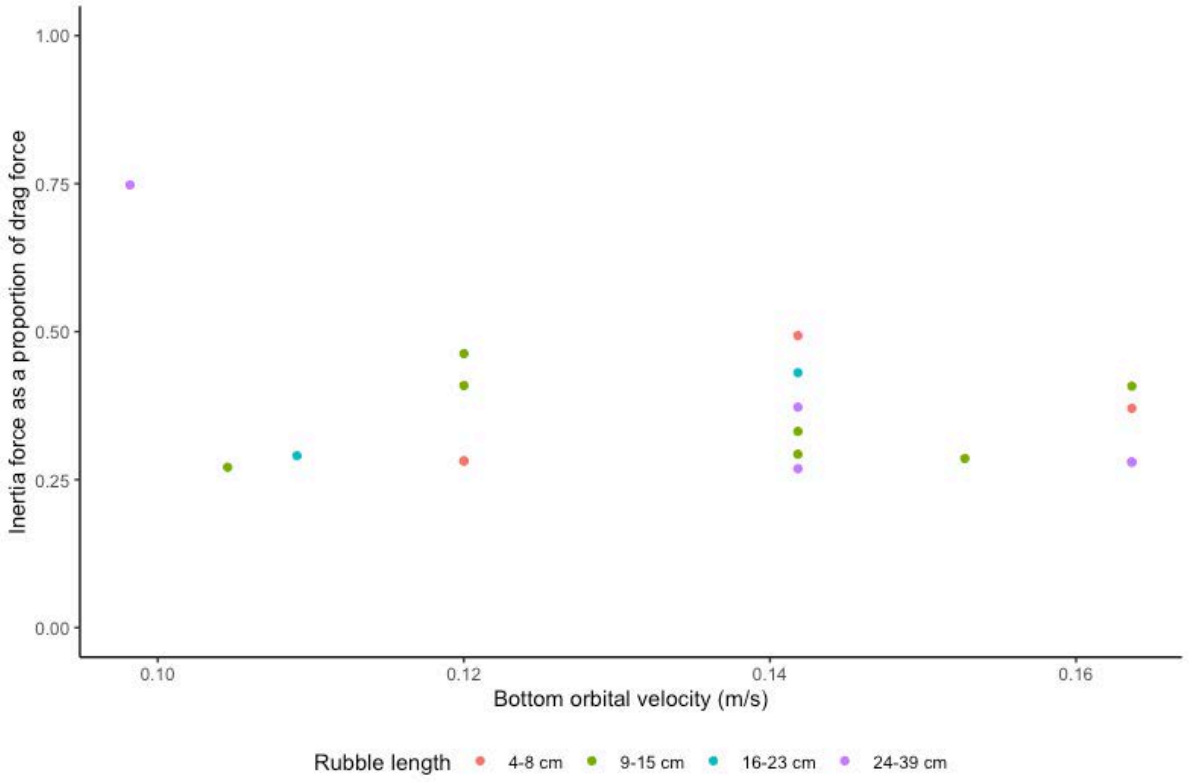

Figure S7 The relationship between bottom orbital velocity and the contribution of inertial force to the total force (i.e., the 24/KC2 value) for the 18 cases where there were flipping/transport movements recorded (not rocking) under conditions that had the potential to be inertia dominant. Colours indicate rubble length categories.

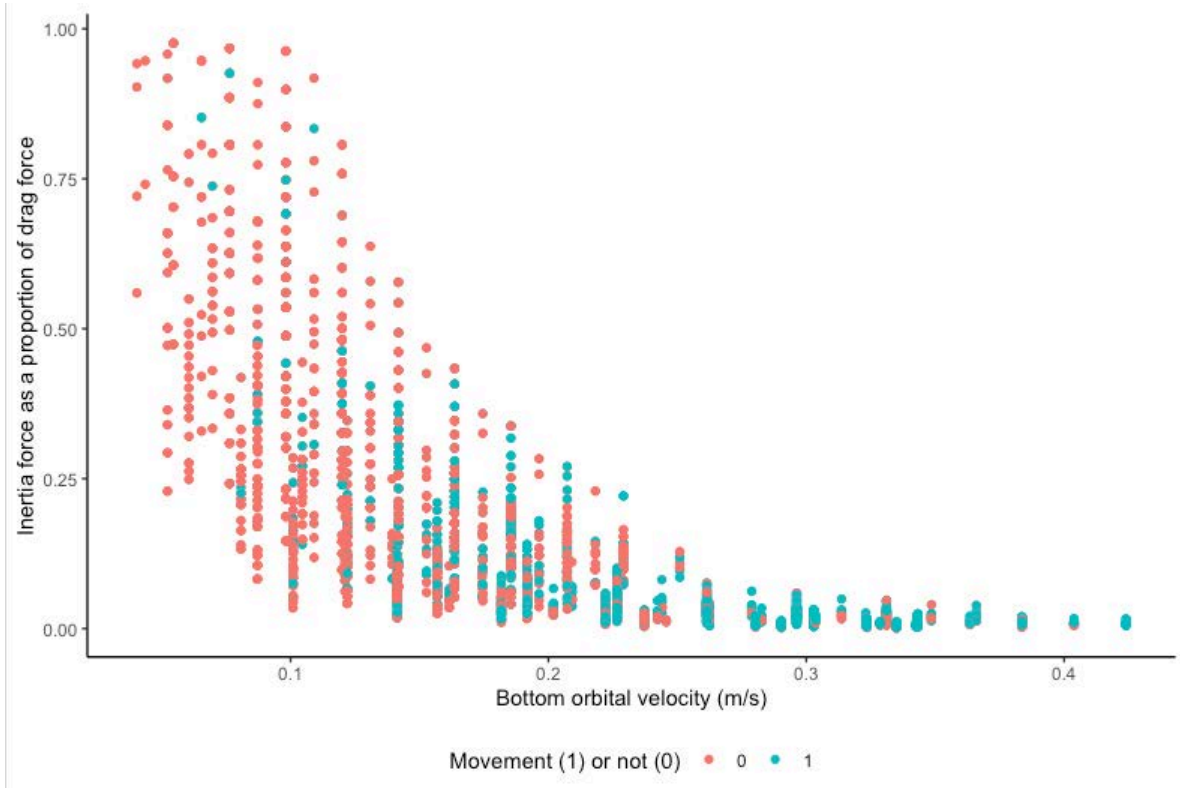

Figure S8 The relationship between bottom orbital velocity and the contribution of inertial force to the total force (i.e., the $24/KC^2$ value) for all cases where F_I/F_D <2. Colours indicate whether rubble moved at all or not.

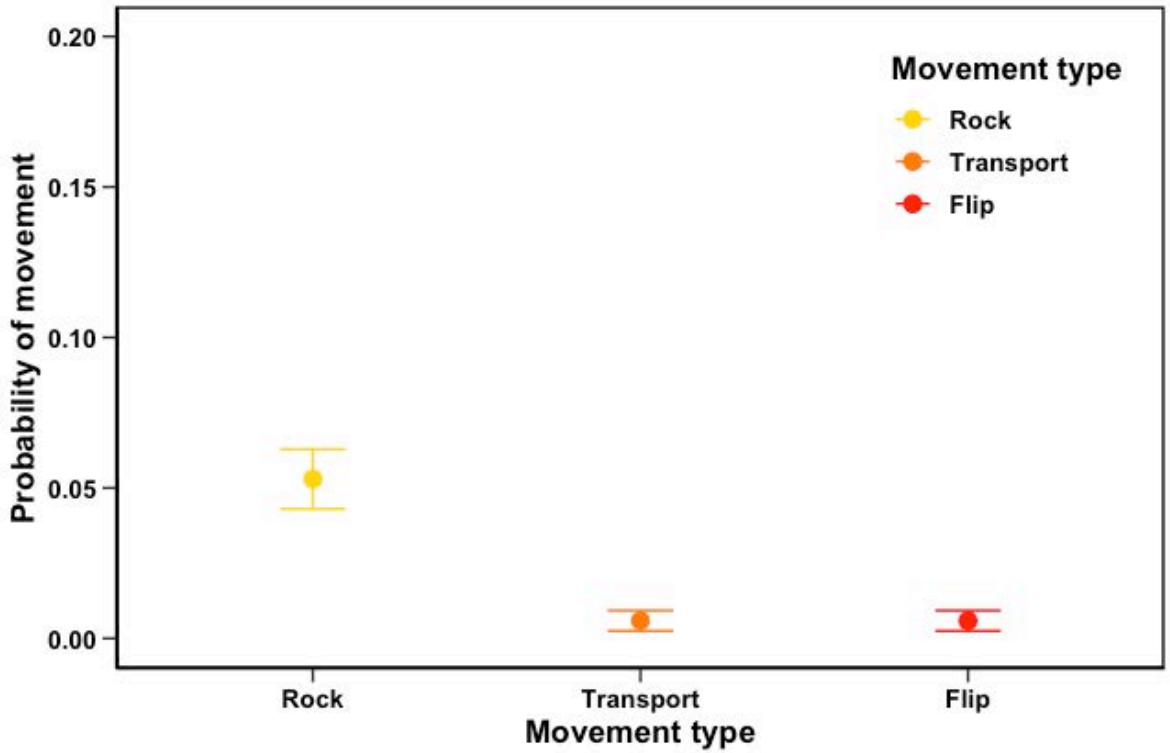

Figure S9 The probability of movement (mean ± SE) for interlocked rubble (across lengths 4-15 cm) according to each movement type.

Table S1/S2 pre-amble: Assuming the drag and inertia coefficients have the same magnitude, the ratio of the maximum inertia force to the maximum drag force is given by Dean and Dalrymple (1991) as:

(1) $\frac{F_I}{F_D} = \frac{\pi^2}{KC} = \alpha$ where $KC = \frac{uT}{\varnothing}$; KC = Keulegan-Carpenter number , u = maximum orbital wave velocity, T = wave period ∅ = rubble diameter

Hence $F_I = \alpha F_D$

The maximum total force is again given by Dean and Dalrymple (1991), noting that the drag and inertia forces are out of phase,

(2) $F_T = F_D + \frac{{F_I}^2}{4.F_D}$ FT = maximum total force, FD = drag force, FI =inertia force

which can be written as $F_T = F_D + \frac{\alpha^2}{4} F_D$ or $F_T = F_D + \frac{24}{KC^2} F_D$

The last term ($\frac{24}{KC^2}$) gives the contribution of the inertia force to the total maximum force as a proportion of the drag force. We consider the inertia component to be potentially significant when it contributes more than 25% of the drag force to the total force. For example, when FI=FD, the contribution to the maximum total force from the inertia force is 0.25FD. It should be noted that this relationship is only valid for $\frac{F_I}{F_D} < 2$, and when $\frac{F_I}{F_D} > 2$, the maximum force is pure inertia (Dean and Dalrymple, 1991).

Table S1: The average coral rubble diameter, wave height, period, water depth, and corresponding velocities (estimated using both the Soulsby cosine approximation and Linear wave theory), inertial force component and bottom orbital excursions for all wave conditions used in determining the relationship between velocity and movement in the wave flume. KC number calculated by 'T (s)' multiplied by 'Velocity (m/s)' divided by 'Rubble diameter (m)'. F_I/F_D calculated by π^2 divided by 'KC'. The KC number provides an indication of the bottom excursions while $24/KC^2$ indicates the contribution of the inertia force to the total maximum force as a proportion of the drag force. Note orbital displacement (S) divided by rubble diameter (D) gives KC/2π, i.e., S/D = KC/(2π).

Depth (m)	H (m)	T (s)	Velocity (Soulsby Cosine Approximation) (m/s)	Velocity (Linear wave theory) (m/s)	Rubble diameter (m)	KC	F_I/F_D	$24/KC^2$	Potential for inertia force to be significant?	Maximum force from?
0.42	0.03	1	0.033	0.032	0.0164	1.996	4.946	6.026	Yes	Inertia

Depth (m)	H (m)	T (s)	Velocity (Soulsby Cosine Approximation) (m/s)	Velocity (Linear wave theory) (m/s)	Rubble diameter (m)	KC	F_I/F_D	$24/KC^2$	Potential for inertia force to be significant?	Maximum force from?
0.42	0.02	1.5	0.035	0.036	0.0164	3.188	3.096	2.361	Yes	Inertia
0.42	0.02	2	0.040	0.041	0.0164	4.925	2.004	0.989	Yes	Inertia
0.42	0.04	1	0.044	0.043	0.0164	2.661	3.709	3.390	Yes	Inertia
0.42	0.03	1.5	0.052	0.054	0.0164	4.782	2.064	1.050	Yes	Inertia
0.42	0.05	1	0.055	0.054	0.0164	3.326	2.967	2.169	Yes	Inertia
0.42	0.03	2	0.061	0.062	0.0164	7.387	1.336	0.440	Yes	Drag
0.42	0.06	1	0.065	0.065	0.0164	3.991	2.473	1.507	Yes	Inertia
0.42	0.04	1.5	0.070	0.072	0.0164	6.376	1.548	0.590	Yes	Drag
0.42	0.07	1	0.076	0.076	0.0164	4.657	2.120	1.107	Yes	Inertia
0.42	0.04	2	0.081	0.083	0.0164	9.850	1.002	0.247	No	Drag
0.42	0.05	1.5	0.087	0.090	0.0164	7.970	1.238	0.378	Yes	Drag
0.42	0.08	1	0.087	0.087	0.0164	5.322	1.855	0.847	Yes	Drag
0.42	0.09	1	0.098	0.097	0.0164	5.987	1.649	0.670	Yes	Drag
0.42	0.05	2	0.101	0.104	0.0164	12.312	0.802	0.158	No	Drag
0.42	0.06	1.5	0.105	0.108	0.0164	9.564	1.032	0.262	Yes	Drag
0.42	0.1	1	0.109	0.108	0.0164	6.652	1.484	0.542	Yes	Drag

Depth (m)	H (m)	T (s)	Velocity (Soulsby Cosine Approximation) (m/s)	Velocity (Linear wave theory) (m/s)	Rubble diameter (m)	KC	F_I/F_D	$24/KC^2$	Potential for inertia force to be significant?	Maximum force from?
0.42	0.11	1	0.120	0.119	0.0164	7.317	1.349	0.448	Yes	Drag
0.42	0.06	2	0.121	0.124	0.0164	14.775	0.668	0.110	No	Drag
0.42	0.07	1.5	0.122	0.126	0.0164	11.158	0.885	0.193	No	Drag
0.42	0.12	1	0.131	0.130	0.0164	7.983	1.236	0.377	Yes	Drag
0.42	0.08	1.5	0.139	0.144	0.0164	12.752	0.774	0.148	No	Drag
0.42	0.07	2	0.141	0.145	0.0164	17.237	0.573	0.081	No	Drag
0.42	0.13	1	0.142	0.141	0.0164	8.648	1.141	0.321	Yes	Drag
0.42	0.14	1	0.153	0.151	0.0164	9.313	1.060	0.277	Yes	Drag
0.42	0.09	1.5	0.157	0.162	0.0164	14.346	0.688	0.117	No	Drag
0.42	0.08	2	0.162	0.166	0.0164	19.700	0.501	0.062	No	Drag
0.42	0.15	1	0.164	0.162	0.0164	9.978	0.989	0.241	No	Drag
0.42	0.1	1.5	0.174	0.180	0.0164	15.940	0.619	0.094	No	Drag
0.42	0.16	1	0.175	0.173	0.0164	10.644	0.927	0.212	No	Drag
0.42	0.09	2	0.182	0.187	0.0164	22.162	0.445	0.049	No	Drag
0.42	0.17	1	0.185	0.184	0.0164	11.309	0.873	0.188	No	Drag
0.42	0.11	1.5	0.192	0.198	0.0164	17.534	0.563	0.078	No	Drag

Depth (m)	H (m)	T (s)	Velocity (Soulsby Cosine Approximation) (m/s)	Velocity (Linear wave theory) (m/s)	Rubble diameter (m)	KC	F_I/F_D	$24/KC^2$	Potential for inertia force to be significant?	Maximum force from?
0.42	0.18	1	0.196	0.195	0.0164	11.974	0.824	0.167	No	Drag
0.42	0.1	2	0.202	0.207	0.0164	24.625	0.401	0.040	No	Drag
0.42	0.19	1	0.207	0.206	0.0164	12.639	0.781	0.150	No	Drag
0.42	0.12	1.5	0.209	0.216	0.0164	19.128	0.516	0.066	No	Drag
0.42	0.2	1	0.218	0.216	0.0164	13.304	0.742	0.136	No	Drag
0.42	0.11	2	0.222	0.228	0.0164	27.087	0.364	0.033	No	Drag
0.42	0.13	1.5	0.227	0.234	0.0164	20.722	0.476	0.056	No	Drag
0.42	0.21	1	0.229	0.227	0.0164	13.970	0.707	0.123	No	Drag
0.42	0.11	2.5	0.237	0.242	0.0164	36.159	0.273	0.018	No	Drag
0.42	0.12	2	0.242	0.249	0.0164	29.550	0.334	0.027	No	Drag
0.42	0.14	1.5	0.244	0.252	0.0164	22.316	0.442	0.048	No	Drag
0.42	0.11	3	0.246	0.249	0.0164	44.941	0.220	0.012	No	Drag
0.42	0.23	1	0.251	0.249	0.0164	15.300	0.645	0.103	No	Drag
0.42	0.15	1.5	0.261	0.270	0.0164	23.910	0.413	0.042	No	Drag
0.42	0.13	2	0.263	0.269	0.0164	32.012	0.308	0.023	No	Drag
0.42	0.16	1.5	0.279	0.288	0.0164	25.504	0.387	0.037	No	Drag

Depth (m)	H (m)	T (s)	Velocity (Soulsby Cosine Approximation) (m/s)	Velocity (Linear wave theory) (m/s)	Rubble diameter (m)	KC	F_I/F_D	$24/KC^2$	Potential for inertia force to be significant?	Maximum force from?
0.42	0.13	2.5	0.280	0.286	0.0164	42.734	0.231	0.013	No	Drag
0.42	0.14	2	0.283	0.290	0.0164	34.475	0.286	0.020	No	Drag
0.42	0.13	3	0.290	0.294	0.0164	53.112	0.186	0.009	No	Drag
0.42	0.17	1.5	0.296	0.306	0.0164	27.098	0.364	0.033	No	Drag
0.42	0.15	2	0.303	0.311	0.0164	36.937	0.267	0.018	No	Drag
0.5	0.17	2	0.304	0.313	0.0164	37.034	0.267	0.017	No	Drag
0.42	0.18	1.5	0.314	0.325	0.0164	28.692	0.344	0.029	No	Drag
0.42	0.16	2	0.323	0.332	0.0164	39.400	0.250	0.015	No	Drag
0.42	0.15	2.5	0.323	0.330	0.0164	49.308	0.200	0.010	No	Drag
0.5	0.17	2.5	0.329	0.336	0.0164	50.098	0.197	0.010	No	Drag
0.42	0.19	1.5	0.331	0.343	0.0164	30.286	0.326	0.026	No	Drag
0.42	0.15	3	0.335	0.340	0.0164	61.283	0.161	0.006	No	Drag
0.5	0.17	3	0.343	0.348	0.0164	62.699	0.157	0.006	No	Drag
0.42	0.17	2	0.343	0.352	0.0164	41.862	0.236	0.014	No	Drag
0.42	0.2	1.5	0.349	0.361	0.0164	31.880	0.310	0.024	No	Drag
0.42	0.18	2	0.363	0.373	0.0164	44.325	0.223	0.012	No	Drag

Depth (m)	H (m)	T (s)	Velocity (Soulsby Cosine Approximation) (m/s)	Velocity (Linear wave theory) (m/s)	Rubble diameter (m)	KC	F_I/F_D	$24/KC^2$	Potential for inertia force to be significant?	Maximum force from?
0.42	0.21	1.5	0.366	0.379	0.0164	33.474	0.295	0.021	No	Drag
0.42	0.17	2.5	0.367	0.373	0.0164	55.882	0.177	0.008	No	Drag
0.42	0.17	3	0.380	0.385	0.0164	69.454	0.142	0.005	No	Drag
0.42	0.19	2	0.384	0.394	0.0164	46.787	0.211	0.011	No	Drag
0.42	0.2	2	0.404	0.414	0.0164	49.250	0.200	0.010	No	Drag
0.42	0.21	2	0.424	0.435	0.0164	51.712	0.191	0.009	No	Drag

Table S2: The average coral rubble diameter, significant wave height (H_S), peak wave period (T_P), water depth, and corresponding velocities (estimated using both Soulsbys cosine approximation and Linear wave theory), inertial force component (accelerations) and bottom orbital excursions for all wave conditions used in determining the relationship between velocity and movement in the field. KC number calculated by 'Max T_P (s)' multiplied by 'Max peak u (m/s)' divided by 'Rubble diameter (m)'. F_I/F_D calculated by π^2 divided by 'KC'. The KC number provides an indication of the bottom excursions while $24/KC^2$ indicates the contribution of the inertia force to the total maximum force as a proportion of the drag force. Note orbital displacement (S) divided by rubble diameter (D) gives $KC/2\pi$, i.e., $S/D = KC/(2\pi)$.

Mon-soon Seas-on	Aspect	Site	Depth category	Day	Mean Depth	Mean H_S (m)	Mean T_P (s)	Mean peak wave length	Mean peak u (m/s)	Max H_S (m)	Max T_P (s)	Max peak wave length	Max peak u (m/s)	Rubble diameter (m)	KC *	F_I/F_D	$24/K^2$	Inertia Signif.?	Max. force from?
NE	L	1	2-3m	1	1.665	0.062	8.820	35.614	0.073	0.076	12.950	52.891	0.088	0.0169	67.423	0.146	0.005	No	Drag
NE	L	1	2-3m	2	1.631	0.060	9.892	39.617	0.071	0.075	13.433	55.047	0.086	0.0169	68.323	0.144	0.005	No	Drag
NE	L	1	2-3m	3	1.634	0.077	8.807	35.292	0.091	0.105	10.169	43.155	0.118	0.0169	71.079	0.139	0.005	No	Drag
NE	L	2	2-3m	1	1.622	0.065	8.587	34.048	0.077	0.128	19.780	68.726	0.180	0.0169	210.180	0.047	0.001	No	Drag
NE	L	2	2-3m	2	1.597	0.059	8.739	34.580	0.071	0.074	12.081	49.884	0.085	0.0169	60.515	0.163	0.007	No	Drag
NE	L	2	2-3m	3	1.600	0.080	8.804	34.883	0.096	0.116	10.588	40.739	0.134	0.0169	83.726	0.118	0.003	No	Drag

Mon-soon Seas-on	Aspect	Site	Depth category	Day	Mean Depth	Mean H_S (m)	Mean T_P (s)	Mean peak wave length	Mean peak u (m/s)	Max H_S (m)	Max T_P (s)	Max peak wave length	Max peak u (m/s)	Rubble diameter (m)	KC*	F_I/F_D	$24/K^2$	Inertia Signif.?	Max. force from?
NE	L	3	2-3m	1	1.592	0.118	5.479	21.475	0.123	0.208	17.308	71.702	0.188	0.0169	192.242	0.051	0.001	No	Drag
NE	L	3	2-3m	2	1.566	0.100	15.223	59.407	0.122	0.142	16.981	68.969	0.163	0.0169	163.769	0.060	0.001	No	Drag
NE	L	3	2-3m	3	1.585	0.124	13.790	54.188	0.150	0.195	15.254	58.881	0.217	0.0169	195.622	0.050	0.001	No	Drag
NE	SE	1	2-3m	1	3.579	0.092	8.551	50.579	0.071	0.135	9.524	54.084	0.103	0.0169	57.829	0.171	0.007	No	Drag
NE	SE	1	2-3m	2	3.583	0.084	10.327	61.170	0.066	0.106	14.634	86.444	0.081	0.0169	70.355	0.140	0.005	No	Drag
NE	SE	1	2-3m	3	3.573	0.078	11.211	66.247	0.062	0.112	12.766	75.711	0.090	0.0169	67.983	0.145	0.005	No	Drag
NE	SE	1	6-7m	1	7.853	0.082	8.509	74.607	0.039	0.124	9.524	82.000	0.059	0.0169	32.980	0.299	0.022	No	Drag
NE	SE	1	6-7m	2	7.857	0.073	10.193	89.437	0.036	0.094	14.400	126.175	0.044	0.0169	37.414	0.264	0.017	No	Drag

Mon-soon Seas-on	Aspect	Site	Depth category	Day	Mean Depth	Mean H_S (m)	Mean T_P (s)	Mean peak wave length	Mean peak u (m/s)	Max H_S (m)	Max T_P (s)	Max peak wave length	Max peak u (m/s)	Rubble diameter (m)	KC*	F_I/F_D	$24/K^2$	Inertia Signif.?	Max. force from?
NE	SE	1	6-7m	3	7.847	0.069	11.293	98.998	0.035	0.098	12.587	111.215	0.051	0.0169	37.978	0.260	0.017	No	Drag
NE	SE	2	2-3m	1	2.450	0.148	6.799	32.952	0.126	0.243	9.424	46.210	0.224	0.0169	124.689	0.079	0.002	No	Drag
NE	SE	2	2-3m	2	2.476	0.135	8.451	41.610	0.128	0.184	10.112	53.242	0.171	0.0169	102.138	0.097	0.002	No	Drag
NE	SE	2	2-3m	3	2.482	0.102	9.159	45.092	0.097	0.171	9.890	51.659	0.156	0.0169	91.273	0.108	0.003	No	Drag
NE	SE	2	6-7m	1	7.013	0.129	6.643	54.882	0.050	0.198	9.626	77.488	0.086	0.0169	48.814	0.202	0.010	No	Drag
NE	SE	2	6-7m	2	7.050	0.116	8.275	68.783	0.057	0.156	10.169	85.184	0.079	0.0169	47.590	0.207	0.011	No	Drag
NE	SE	2	6-7m	3	7.056	0.088	9.140	75.980	0.046	0.154	10.227	88.103	0.080	0.0169	48.461	0.204	0.010	No	Drag
NE	SE	3	2-3m	1	2.824	0.081	9.700	50.946	0.072	0.112	10.169	54.648	0.095	0.0169	57.010	0.173	0.007	No	Drag

Mon-soon Seas-on	Aspect	Site	Depth category	Day	Mean Depth	Mean H_S (m)	Mean T_P (s)	Mean peak wave length	Mean peak u (m/s)	Max H_S (m)	Max T_P (s)	Max peak wave length	Max peak u (m/s)	Rubble diameter (m)	KC*	F_I/F_D	$24/K^2$	Inertia Signif.?	Max. force from?
NE	SE	3	2-3m	2	2.854	0.074	9.740	51.437	0.065	0.113	11.043	56.263	0.098	0.0169	63.857	0.155	0.006	No	Drag
NE	SE	3	2-3m	3	2.837	0.078	9.404	49.573	0.069	0.109	10.345	54.573	0.097	0.0169	59.305	0.166	0.007	No	Drag
NE	SE	3	6-7m	1	7.157	0.072	9.718	81.362	0.038	0.101	10.286	86.772	0.051	0.0169	31.005	0.318	0.025	No	Drag
NE	SE	3	6-7m	2	7.188	0.065	9.652	80.975	0.033	0.102	11.180	92.480	0.052	0.0169	34.667	0.285	0.020	No	Drag
NE	SE	3	6-7m	3	7.170	0.069	9.411	78.893	0.036	0.097	10.345	86.677	0.049	0.0169	30.044	0.329	0.027	No	Drag
NE	W	1	2-3m	1	1.899	0.087	4.111	17.872	0.076	0.146	8.531	40.199	0.136	0.0169	68.887	0.143	0.005	No	Drag
NE	W	1	2-3m	2	1.917	0.126	4.052	17.324	0.108	0.274	8.182	35.495	0.215	0.0169	104.292	0.095	0.002	No	Drag
NE	W	1	2-3m	3	1.898	0.110	3.561	15.215	0.093	0.223	7.930	31.228	0.194	0.0169	90.852	0.109	0.003	No	Drag

Mon-soon Seas-on	Aspect	Site	Depth category	Day	Mean Depth	Mean H_S (m)	Mean T_P (s)	Mean peak wave length	Mean peak u (m/s)	Max H_S (m)	Max T_P (s)	Max peak wave length	Max peak u (m/s)	Rubble diameter (m)	KC *	F_I/F_D	$24/K^2$	Inertia Signif.?	Max. force from?
NE	W	1	6-7m	1	7.774	0.068	3.656	31.897	0.011	0.116	4.072	35.785	0.016	0.0169	3.878	2.545	1.596	Yes	Inertia
NE	W	1	6-7m	2	7.735	0.054	4.434	38.699	0.011	0.086	8.491	74.476	0.028	0.0169	13.872	0.711	0.125	No	Drag
NE	W	1	6-7m	3	7.742	0.077	4.706	40.904	0.015	0.165	8.654	73.682	0.032	0.0169	16.568	0.596	0.087	No	Drag
NE	W	2	2-3m	1	2.778	0.123	3.179	16.591	0.072	0.215	3.888	19.710	0.130	0.0169	29.947	0.330	0.027	No	Drag
NE	W	2	2-3m	2	2.807	0.172	3.537	18.548	0.111	0.227	3.830	20.804	0.142	0.0169	32.288	0.306	0.023	No	Drag
NE	W	2	2-3m	3	2.806	0.154	3.491	18.292	0.098	0.208	3.711	19.600	0.125	0.0169	27.542	0.358	0.032	No	Drag
NE	W	2	6-7m	1	7.176	0.074	3.736	31.329	0.012	0.142	7.860	65.564	0.025	0.0169	11.712	0.843	0.175	No	Drag
NE	W	2	6-7m	2	7.200	0.110	3.524	29.597	0.018	0.149	3.982	32.925	0.029	0.0169	6.947	1.421	0.497	Yes	Drag

Mon-soon Seas-on	Aspect	Site	Depth category	Day	Mean Depth	Mean H_S (m)	Mean T_P (s)	Mean peak wave length	Mean peak u (m/s)	Max H_S (m)	Max T_P (s)	Max peak wave length	Max peak u (m/s)	Rubble diameter (m)	KC*	F_I/F_D	$24/K^2$	Inertia Signif.?	Max. force from?
NE	W	2	6-7m	3	7.074	0.105	3.490	29.052	0.018	0.165	3.696	30.982	0.026	0.0169	5.654	1.746	0.751	Yes	Drag
NE	W	3	2-3m	1	2.953	0.066	5.332	28.276	0.041	0.123	12.000	62.969	0.061	0.0169	43.096	0.229	0.013	No	Drag
NE	W	3	2-3m	2	2.994	0.062	5.698	30.627	0.039	0.114	17.308	93.516	0.064	0.0169	65.149	0.151	0.006	No	Drag
NE	W	3	2-3m	3	2.965	0.047	7.621	41.145	0.036	0.077	11.613	66.607	0.050	0.0169	34.456	0.286	0.020	No	Drag
NE	W	3	6-7m	1	NA	NA	NA	NA	0.007	NA	NA	NA	0.011	0.0169	NA	NA	NA	NA	Drag
NE	W	3	6-7m	2	NA	NA	NA	NA	0.007	NA	NA	NA	0.011	0.0169	NA	NA	NA	NA	Drag
NE	W	3	6-7m	3	NA	NA	NA	NA	0.006	NA	NA	NA	0.009	0.0169	NA	NA	NA	NA	Drag
W	L	1	2-3m	1	1.315	0.139	9.588	34.373	0.185	0.191	10.714	42.328	0.233	0.0169	147.426	0.067	0.001	No	Drag
W	L	1	2-3m	2	1.378	0.140	9.335	34.183	0.182	0.195	10.651	43.262	0.227	0.0169	143.078	0.069	0.001	No	Drag

Mon-soon Seas-on	Aspect	Site	Depth category	Day	Mean Depth	Mean H_S (m)	Mean T_P (s)	Mean peak wave length	Mean peak u (m/s)	Max H_S (m)	Max T_P (s)	Max peak wave length	Max peak u (m/s)	Rubble diameter (m)	KC*	F_I/F_D	$24/K^2$	Inertia Signif.?	Max. force from?
W	L	1	2-3m	3	1.401	0.128	8.934	33.040	0.164	0.172	10.000	39.024	0.211	0.0169	124.969	0.079	0.002	No	Drag
W	L	2	2-3m	1	1.391	0.157	9.680	35.655	0.204	0.210	10.909	44.685	0.246	0.0169	158.973	0.062	0.001	No	Drag
W	L	2	2-3m	2	1.447	0.156	9.304	34.930	0.198	0.207	10.112	42.220	0.242	0.0169	144.934	0.068	0.001	No	Drag
W	L	2	2-3m	3	1.468	0.139	8.970	33.941	0.175	0.182	9.730	39.224	0.218	0.0169	125.651	0.079	0.002	No	Drag
W	L	3	2-3m	1	1.373	0.176	8.653	31.676	0.228	0.230	9.730	37.456	0.293	0.0169	168.641	0.059	0.001	No	Drag
W	L	3	2-3m	2	1.374	0.161	8.341	30.521	0.209	0.206	8.867	33.752	0.253	0.0169	132.951	0.074	0.001	No	Drag
W	L	3	2-3m	3	1.388	0.144	8.248	30.377	0.186	0.191	8.955	34.905	0.242	0.0169	128.460	0.077	0.001	No	Drag
W	SE	1	2-3m	1	3.036	0.110	12.924	70.535	0.096	0.133	19.780	109.675	0.110	0.0169	129.061	0.076	0.001	No	Drag

Mon-soon Seas-on	Aspect	Site	Depth category	Day	Mean Depth	Mean H_S (m)	Mean T_P (s)	Mean peak wave length	Mean peak u (m/s)	Max H_S (m)	Max T_P (s)	Max peak wave length	Max peak u (m/s)	Rubble diameter (m)	KC *	F_I/F_D	$24/K^2$	Inertia Signif.?	Max. force from?
W	SE	1	2-3m	2	3.055	0.125	9.606	52.575	0.107	0.141	12.500	67.796	0.123	0.0169	91.314	0.108	0.003	No	Drag
W	SE	1	2-3m	3	3.054	0.120	9.306	50.885	0.103	0.141	12.245	66.861	0.117	0.0169	84.941	0.116	0.003	No	Drag
W	SE	1	6-7m	1	7.664	0.095	13.844	120.104	0.050	0.116	19.565	172.839	0.058	0.0169	67.507	0.146	0.005	No	Drag
W	SE	1	6-7m	2	7.685	0.108	9.721	84.376	0.054	0.121	12.587	108.860	0.060	0.0169	45.025	0.219	0.012	No	Drag
W	SE	1	6-7m	3	7.684	0.105	9.184	79.701	0.052	0.124	12.329	106.465	0.060	0.0169	44.087	0.224	0.012	No	Drag
W	SE	2	2-3m	1	2.188	0.271	11.437	52.925	0.282	0.361	12.245	57.936	0.398	0.0169	288.198	0.034	0.000	No	Drag
W	SE	2	2-3m	2	2.158	0.251	11.134	51.172	0.263	0.294	11.842	56.007	0.330	0.0169	231.195	0.043	0.000	No	Drag
W	SE	2	2-3m	3	2.292	0.226	10.858	51.457	0.228	0.295	11.392	54.940	0.311	0.0169	209.406	0.047	0.001	No	Drag

Mon-soon Seas-on	Aspect	Site	Depth category	Day	Mean Depth	Mean H_S (m)	Mean T_P (s)	Mean peak wave length	Mean peak u (m/s)	Max H_S (m)	Max T_P (s)	Max peak wave length	Max peak u (m/s)	Rubble diameter (m)	KC*	F_I/F_D	$24/K^2$	Inertia Signif.?	Max. force from?
W	SE	2	6-7m	1	6.882	0.240	11.502	94.459	0.133	0.327	12.414	100.815	0.185	0.0169	136.178	0.072	0.001	No	Drag
W	SE	2	6-7m	2	6.560	0.225	11.140	89.320	0.128	0.271	12.000	100.132	0.155	0.0169	110.097	0.090	0.002	No	Drag
W	SE	2	6-7m	3	6.590	0.214	10.675	85.791	0.120	0.273	11.392	93.052	0.156	0.0169	105.302	0.094	0.002	No	Drag
W	SE	3	2-3m	1	NA	NA	NA	NA	0.181	NA	NA	NA	0.260	0.0169	NA	NA	NA	NA	Drag
W	SE	3	2-3m	2	NA	NA	NA	NA	0.174	NA	NA	NA	0.266	0.0169	NA	NA	NA	NA	Drag
W	SE	3	2-3m	3	NA	NA	NA	NA	0.235	NA	NA	NA	0.299	0.0169	NA	NA	NA	NA	Drag
W	SE	3	6-7m	1	7.762	0.175	9.976	87.021	0.088	0.257	12.857	109.219	0.126	0.0169	95.799	0.103	0.003	No	Drag
W	SE	3	6-7m	2	7.792	0.169	9.879	86.318	0.084	0.261	11.321	101.470	0.129	0.0169	86.220	0.114	0.003	No	Drag
W	SE	3	6-7m	3	7.801	0.227	10.121	88.478	0.114	0.289	10.909	95.312	0.145	0.0169	93.324	0.106	0.003	No	Drag

Mon-soon Seas-on	Aspect	Site	Depth category	Day	Mean Depth	Mean H_S (m)	Mean T_P (s)	Mean peak wave length	Mean peak u (m/s)	Max H_S (m)	Max T_P (s)	Max peak wave length	Max peak u (m/s)	Rubble diameter (m)	KC*	F_I/F_D	$24/K^2$	Inertia Signif.?	Max. force from?
W	W	1	2-3m	1	2.908	0.118	9.518	50.807	0.103	0.157	10.651	59.955	0.129	0.0169	81.547	0.121	0.004	No	Drag
W	W	1	2-3m	2	2.922	0.101	9.055	48.430	0.088	0.139	10.465	57.561	0.114	0.0169	70.433	0.140	0.005	No	Drag
W	W	1	2-3m	3	2.920	0.103	8.780	46.912	0.089	0.158	10.345	58.696	0.133	0.0169	81.487	0.121	0.004	No	Drag
W	W	1	6-7m	1	7.390	0.105	9.496	80.811	0.054	0.142	10.651	90.062	0.069	0.0169	43.523	0.227	0.013	No	Drag
W	W	1	6-7m	2	7.405	0.088	9.110	77.610	0.044	0.121	10.000	85.242	0.060	0.0169	35.659	0.277	0.019	No	Drag
W	W	1	6-7m	3	7.403	0.089	8.868	75.515	0.044	0.138	9.890	83.956	0.070	0.0169	40.680	0.243	0.015	No	Drag
W	W	2	2-3m	1	2.500	0.133	9.487	46.959	0.127	0.179	10.778	55.151	0.170	0.0169	108.109	0.091	0.002	No	Drag
W	W	2	2-3m	2	2.501	0.148	9.717	48.077	0.141	0.192	10.651	52.914	0.184	0.0169	115.996	0.085	0.002	No	Drag

Mon-soon Seas-on	Aspect	Site	Depth category	Day	Mean Depth	Mean H_S (m)	Mean T_P (s)	Mean peak wave length	Mean peak u (m/s)	Max H_S (m)	Max T_P (s)	Max peak wave length	Max peak u (m/s)	Rubble diameter (m)	KC *	F_I/F_D	$24/K^2$	Inertia Signif.?	Max. force from?
W	W	2	2-3m	3	2.515	0.158	9.407	46.714	0.149	0.234	10.526	54.952	0.212	0.0169	132.212	0.075	0.001	No	Drag
W	W	2	6-7m	1	6.469	0.122	9.593	76.394	0.068	0.166	10.778	86.945	0.091	0.0169	58.137	0.170	0.007	No	Drag
W	W	2	6-7m	2	6.470	0.134	9.848	78.409	0.075	0.172	11.180	89.536	0.098	0.0169	65.074	0.152	0.006	No	Drag
W	W	2	6-7m	3	6.484	0.141	9.367	74.690	0.078	0.210	10.526	83.834	0.114	0.0169	71.066	0.139	0.005	No	Drag
W	W	3	2-3m	1	3.011	0.285	7.536	41.083	0.207	0.741	10.976	60.068	0.429	0.0169	278.803	0.035	0.000	No	Drag
W	W	3	2-3m	2	2.959	0.307	8.220	44.189	0.252	0.544	9.626	53.258	0.345	0.0169	196.585	0.050	0.001	No	Drag
W	W	3	2-3m	3	2.981	0.256	8.331	45.006	0.213	0.373	9.836	54.284	0.289	0.0169	168.299	0.059	0.001	No	Drag
W	W	3	6-7m	1	7.773	0.247	7.846	68.549	0.087	0.724	11.613	101.601	0.155	0.0169	106.377	0.093	0.002	No	Drag

Mon-soon Seas-on	Aspect	Site	Depth category	Day	Mean Depth	Mean H_S (m)	Mean T_P (s)	Mean peak wave length	Mean peak u (m/s)	Max H_S (m)	Max T_P (s)	Max peak wave length	Max peak u (m/s)	Rubble diameter (m)	KC*	F_I/F_D	$24/K^2$	Inertia Signif.?	Max. force from?
W	W	3	6-7m	2	7.722	0.270	8.224	71.496	0.120	0.456	9.626	84.625	0.168	0.0169	95.804	0.103	0.003	No	Drag
W	W	3	6-7m	3	7.744	0.222	7.625	66.437	0.088	0.306	9.783	85.913	0.127	0.0169	73.558	0.134	0.004	No	Drag

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Table S3 The 10%, 50% and 90% thresholds for transport, averaged across sizes 4-23 cm and both morphologies and substrates, for model "fl.t.thresh".

Probability	Velocity (m/s)	SE	lower	upper
0.1	0.172	0.004	0.165	0.179
0.5	0.303	0.003	0.298	0.309
0.9	0.435	0.006	0.423	0.446

Table S4 The 10%, 50% and 90% thresholds for flipping, averaged across sizes 4-23 cm and both morphologies and substrates, for model "fl.f.threshNOXL".

Probability	Velocity (m/s)	SE	lower	upper
0.1	0.181	0.004	0.173	0.189
0.5	0.336	0.004	0.329	0.344
0.9	0.491	0.009	0.474	0.508

Table S5 Anova table of model "fl.r.global" describing the effect of velocity, rubble size, branchiness and underlying substrate on the probability of rocking motions of rubble pieces.

Model term	LR χ^2	df	p-value (>χ^2)
calculated.velocity_corrected	1012.400	1	<0.001
size	8.692	3	0.034
substrate	0.732	1	0.392
branched	191.305	1	<0.001
calculated.velocity_corrected:size	92.921	3	<0.001
calculated.velocity_corrected:substrate	33.668	1	<0.001

Model term	LR χ^2	df	p-value (>χ^2)
calculated.velocity_corrected:branched	0.684	1	0.408
size:substrate	20.401	3	<0.001
size:branched	90.655	3	<0.001
substrate:branched	33.544	1	<0.001
calculated.velocity_corrected:size:branched	55.330	3	<0.001
calculated.velocity_corrected:size:substrate	17.765	3	<0.001

Table S6 Pairwise comparisons between branched and unbranched rubble for 4 rubble size categories and 4 levels of continuous variable 'velocity' (0.01 m/s, 0.2 m/s (mean), 0.3 m/s, 0.4 m/s) for model "fl.r.global".

Contrast	Rubble size	Near-bed wave orbital velocity (m/s)	Odds Ratio	SE	df	z-ratio	p-value
Unbranched / Branched	4-8 cm	0.1	6.916	1.668	Inf	8.019	<0.001
Unbranched / Branched	9-15 cm	0.1	1.795	0.435	Inf	2.414	0.016
Unbranched / Branched	16-23 cm	0.1	3.134	0.778	Inf	4.605	<0.001
Unbranched / Branched	24-39 cm	0.1	4.378	0.989	Inf	6.534	<0.001
Unbranched / Branched	4-8 cm	0.2	6.875	1.254	Inf	10.568	<0.001
Unbranched / Branched	9-15 cm	0.2	4.462	0.977	Inf	6.829	<0.001
Unbranched / Branched	16-23 cm	0.2	1.236	0.202	Inf	1.292	0.196
Unbranched / Branched	24-39 cm	0.2	9.042	1.708	Inf	11.659	<0.001
Unbranched / Branched	4-8 cm	0.3	6.834	2.396	Inf	5.483	<0.001

Contrast	Rubble size	Near-bed wave orbital velocity (m/s)	Odds Ratio	SE	df	z-ratio	p-value
Unbranched / Branched	9-15 cm	0.3	11.093	4.560	Inf	5.855	<0.001
Unbranched / Branched	16-23 cm	0.3	0.487	0.115	Inf	-3.058	0.002
Unbranched / Branched	24-39 cm	0.3	18.676	6.167	Inf	8.864	<0.001
Unbranched / Branched	4-8 cm	0.4	6.794	3.885	Inf	3.351	0.001
Unbranched / Branched	9-15 cm	0.4	27.577	17.907	Inf	5.108	<0.001
Unbranched / Branched	16-23 cm	0.4	0.192	0.074	Inf	-4.303	<0.001
Unbranched / Branched	24-39 cm	0.4	38.572	20.088	Inf	7.014	<0.001
Unbranched / Branched	4-8 cm	0.1	6.916	1.668	Inf	8.019	<0.001
Unbranched / Branched	9-15 cm	0.1	1.795	0.435	Inf	2.414	0.016
Unbranched / Branched	16-23 cm	0.1	3.134	0.778	Inf	4.605	<0.001
Unbranched / Branched	24-39 cm	0.1	4.378	0.989	Inf	6.534	<0.001
Unbranched / Branched	4-8 cm	0.2	6.875	1.254	Inf	10.568	<0.001
Unbranched / Branched	9-15 cm	0.2	4.462	0.977	Inf	6.829	<0.001
Unbranched / Branched	16-23 cm	0.2	1.236	0.202	Inf	1.292	0.196
Unbranched / Branched	24-39 cm	0.2	9.042	1.708	Inf	11.659	<0.001
Unbranched / Branched	4-8 cm	0.3	6.834	2.396	Inf	5.483	<0.001
Unbranched / Branched	9-15 cm	0.3	11.093	4.560	Inf	5.855	<0.001
Unbranched / Branched	16-23 cm	0.3	0.487	0.115	Inf	-3.058	0.002
Unbranched / Branched	24-39 cm	0.3	18.676	6.167	Inf	8.864	<0.001
Unbranched / Branched	4-8 cm	0.4	6.794	3.885	Inf	3.351	0.001
Unbranched / Branched	9-15 cm	0.4	27.577	17.907	Inf	5.108	<0.001
Unbranched / Branched	16-23 cm	0.4	0.192	0.074	Inf	-4.303	<0.001
Unbranched / Branched	24-39 cm	0.4	38.572	20.088	Inf	7.014	<0.001

Table S7 Pairwise comparisons between rubble and sand substrate for 4 rubble size categories and 4 levels of continuous variable 'velocity' (0.01 m/s, 0.2 m/s (mean), 0.3 m/s, 0.4 m/s) for model "fl.r.global".

Contrast	Rubble size	Near-bed wave orbital velocity (m/s)	Odds Ratio	SE	df	z-ratio	p-value
Rubble / Sand	4-8 cm	0.1	2.354	0.609	Inf	3.313	0.001
Rubble / Sand	9-15 cm	0.1	1.130	0.286	Inf	0.482	0.630
Rubble / Sand	16-23 cm	0.1	1.441	0.392	Inf	1.343	0.179
Rubble / Sand	24-39 cm	0.1	2.062	0.556	Inf	2.686	0.007
Rubble / Sand	4-8 cm	0.2	0.429	0.092	Inf	-3.967	<0.001
Rubble / Sand	9-15 cm	0.2	0.613	0.106	Inf	-2.839	0.005
Rubble / Sand	16-23 cm	0.2	1.033	0.174	Inf	0.190	0.849
Rubble / Sand	24-39 cm	0.2	1.386	0.232	Inf	1.952	0.051
Rubble / Sand	4-8 cm	0.3	0.078	0.038	Inf	-5.227	<0.001
Rubble / Sand	9-15 cm	0.3	0.333	0.076	Inf	-4.800	<0.001
Rubble / Sand	16-23 cm	0.3	0.740	0.165	Inf	-1.355	0.176
Rubble / Sand	24-39 cm	0.3	0.931	0.177	Inf	-0.375	0.708
Rubble / Sand	4-8 cm	0.4	0.014	0.011	Inf	-5.299	<0.001
Rubble / Sand	9-15 cm	0.4	0.181	0.066	Inf	-4.701	<0.001
Rubble / Sand	16-23 cm	0.4	0.530	0.196	Inf	-1.715	0.086
Rubble / Sand	24-39 cm	0.4	0.626	0.196	Inf	-1.500	0.134
Rubble / Sand	4-8 cm	0.1	2.354	0.609	Inf	3.313	0.001
Rubble / Sand	9-15 cm	0.1	1.130	0.286	Inf	0.482	0.630
Rubble / Sand	16-23 cm	0.1	1.441	0.392	Inf	1.343	0.179
Rubble / Sand	24-39 cm	0.1	2.062	0.556	Inf	2.686	0.007
Rubble / Sand	4-8 cm	0.2	0.429	0.092	Inf	-3.967	<0.001
Rubble / Sand	9-15 cm	0.2	0.613	0.106	Inf	-2.839	0.005

Contrast	Rubble size	Near-bed wave orbital velocity (m/s)	Odds Ratio	SE	df	z-ratio	p-value
Rubble / Sand	16-23 cm	0.2	1.033	0.174	Inf	0.190	0.849
Rubble / Sand	24-39 cm	0.2	1.386	0.232	Inf	1.952	0.051
Rubble / Sand	4-8 cm	0.3	0.078	0.038	Inf	-5.227	<0.001
Rubble / Sand	9-15 cm	0.3	0.333	0.076	Inf	-4.800	<0.001
Rubble / Sand	16-23 cm	0.3	0.740	0.165	Inf	-1.355	0.176
Rubble / Sand	24-39 cm	0.3	0.931	0.177	Inf	-0.375	0.708
Rubble / Sand	4-8 cm	0.4	0.014	0.011	Inf	-5.299	<0.001
Rubble / Sand	9-15 cm	0.4	0.181	0.066	Inf	-4.701	<0.001
Rubble / Sand	16-23 cm	0.4	0.530	0.196	Inf	-1.715	0.086
Rubble / Sand	24-39 cm	0.4	0.626	0.196	Inf	-1.500	0.134

Table S8 Pairwise comparisons between four different rubble size categories for each level of branchiness and 4 levels of continuous variable 'velocity' (0.01 m/s, 0.2 m/s (mean), 0.3 m/s, 0.4 m/s) for model described in Table S2.

Size comparison	Rubble branchiness	Near-bed wave orbital velocity (m/s)	Odds Ratio	SE	df	z-ratio	p-value
4-8 cm / 9-15 cm	Unbranched	0.1	0.7948	2.03E-01	Inf	-0.901	0.8043
4-8 cm / 16-23 cm	Unbranched	0.1	0.7549	1.73E-01	Inf	-1.23	0.6078
4-8 cm / 24-39 cm	Unbranched	0.1	0.6975	1.56E-01	Inf	-1.612	0.3715
9-15 cm / 16-23 cm	Unbranched	0.1	0.9498	2.68E-01	Inf	-0.182	0.9979
9-15 cm / 24-39 cm	Unbranched	0.1	0.8777	2.44E-01	Inf	-0.47	0.9657
16-23 cm / 24-39 cm	Unbranched	0.1	0.9241	2.36E-01	Inf	-0.309	0.9898
4-8 cm / 9-15 cm	Branched	0.1	0.2063	5.38E-02	Inf	-6.057	<.0001
4-8 cm / 16-23 cm	Branched	0.1	0.3421	9.55E-02	Inf	-3.843	0.0007

Size comparison	Rubble branchiness	Near-bed wave orbital velocity (m/s)	Odds Ratio	SE	df	z-ratio	p-value
4-8 cm / 24-39 cm	Branched	0.1	0.4416	1.21E-01	Inf	-2.984	0.0151
9-15 cm / 16-23 cm	Branched	0.1	1.6584	3.72E-01	Inf	2.253	0.1093
9-15 cm / 24-39 cm	Branched	0.1	2.1406	4.70E-01	Inf	3.463	0.003
16-23 cm / 24-39 cm	Branched	0.1	1.2908	3.13E-01	Inf	1.053	0.7181
4-8 cm / 9-15 cm	Unbranched	0.2	1.8795	4.74E-01	Inf	2.502	0.0596
4-8 cm / 16-23 cm	Unbranched	0.2	6.5106	1.31E+00	Inf	9.294	<.0001
4-8 cm / 24-39 cm	Unbranched	0.2	1.5403	3.47E-01	Inf	1.916	0.2214
9-15 cm / 16-23 cm	Unbranched	0.2	3.4641	8.42E-01	Inf	5.113	<.0001
9-15 cm / 24-39 cm	Unbranched	0.2	0.8196	2.16E-01	Inf	-0.755	0.8744
16-23 cm / 24-39 cm	Unbranched	0.2	0.2366	4.98E-02	Inf	-6.849	<.0001
4-8 cm / 9-15 cm	Branched	0.2	1.2199	1.86E-01	Inf	1.301	0.5625
4-8 cm / 16-23 cm	Branched	0.2	1.1702	1.89E-01	Inf	0.973	0.7651
4-8 cm / 24-39 cm	Branched	0.2	2.026	3.25E-01	Inf	4.395	0.0001
9-15 cm / 16-23 cm	Branched	0.2	0.9593	1.28E-01	Inf	-0.311	0.9896
9-15 cm / 24-39 cm	Branched	0.2	1.6607	2.20E-01	Inf	3.821	0.0008
16-23 cm / 24-39 cm	Branched	0.2	1.7312	2.47E-01	Inf	3.847	0.0007
4-8 cm / 9-15 cm	Unbranched	0.3	4.4445	2.29E+00	Inf	2.895	0.0198
4-8 cm / 16-23 cm	Unbranched	0.3	56.1546	2.20E+01	Inf	10.288	<.0001
4-8 cm / 24-39 cm	Unbranched	0.3	3.4014	1.58E+00	Inf	2.638	0.0415
9-15 cm / 16-23 cm	Unbranched	0.3	12.6346	5.66E+00	Inf	5.666	<.0001
9-15 cm / 24-39 cm	Unbranched	0.3	0.7653	3.92E-01	Inf	-0.522	0.9537
16-23 cm / 24-39 cm	Unbranched	0.3	0.0606	2.27E-02	Inf	-7.481	<.0001
4-8 cm / 9-15 cm	Branched	0.3	7.2143	2.06E+00	Inf	6.92	<.0001
4-8 cm / 16-23 cm	Branched	0.3	4.003	1.18E+00	Inf	4.718	<.0001

Size comparison	Rubble branchiness	Near-bed wave orbital velocity (m/s)	Odds Ratio	SE	df	z-ratio	p-value
4-8 cm / 24-39 cm	Branched	0.3	9.2948	2.61E+00	Inf	7.941	<.0001
9-15 cm / 16-23 cm	Branched	0.3	0.5549	9.15E-02	Inf	-3.572	0.002
9-15 cm / 24-39 cm	Branched	0.3	1.2884	1.81E-01	Inf	1.806	0.2704
16-23 cm / 24-39 cm	Branched	0.3	2.3219	3.62E-01	Inf	5.4	<.0001
4-8 cm / 9-15 cm	Unbranched	0.4	10.5103	8.61E+00	Inf	2.872	0.0212
4-8 cm / 16-23 cm	Unbranched	0.4	484.336	3.03E+02	Inf	9.897	<.0001
4-8 cm / 24-39 cm	Unbranched	0.4	7.511	5.54E+00	Inf	2.736	0.0316
9-15 cm / 16-23 cm	Unbranched	0.4	46.0819	3.27E+01	Inf	5.396	<.0001
9-15 cm / 24-39 cm	Unbranched	0.4	0.7146	5.79E-01	Inf	-0.415	0.9759
16-23 cm / 24-39 cm	Unbranched	0.4	0.0155	9.22E-03	Inf	-7.004	<.0001
4-8 cm / 9-15 cm	Branched	0.4	42.6628	2.10E+01	Inf	7.623	<.0001
4-8 cm / 16-23 cm	Branched	0.4	13.6931	6.97E+00	Inf	5.144	<.0001
4-8 cm / 24-39 cm	Branched	0.4	42.6438	2.06E+01	Inf	7.756	<.0001
9-15 cm / 16-23 cm	Branched	0.4	0.321	8.98E-02	Inf	-4.06	0.0003
9-15 cm / 24-39 cm	Branched	0.4	0.9996	2.33E-01	Inf	-0.002	1
16-23 cm / 24-39 cm	Branched	0.4	3.1143	8.28E-01	Inf	4.272	0.0001

59 **Table S9 Anova table of model "fl.t.global" describing the effect of velocity, rubble size, branchiness and underlying substrate on the probability of transport of rubble pieces.**

Model term	LR χ^2	df	p-value (>χ^2)
calculated.velocity_corrected	2188.332	1	<0.001
size	175.957	3	<0.001
substrate	2.292	1	0.130

Model term	LR χ^2	df	p-value (>χ^2)
branched	289.922	1	<0.001
calculated.velocity_corrected:size	50.249	3	<0.001
calculated.velocity_corrected:substrate	8.485	1	0.004
calculated.velocity_corrected:branched	0.285	1	0.593
size:substrate	25.755	3	<0.001
size:branched	21.922	3	<0.001
substrate:branched	0.762	1	0.383
calculated.velocity_corrected:size:branched	17.569	3	0.001
calculated.velocity_corrected:size:substrate	8.940	3	0.030

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61 **Table S10 Pairwise comparisons between two levels of branchiness for 4 rubble size classes and 4 levels of continuous variable 'velocity' (0.01 m/s, 0.2 m/s (mean), 0.3 m/s, 0.4 m/s) for**
62 **model described in Table S6.**

Branchiness comparison	Rubble size	Near-bed wave orbital velocity (m/s)	Odds Ratio	SE	df	z-ratio	p-value
Unbranched / Branched	4-8 cm	0.1	8.263	3.257	Inf	5.358	<0.001
Unbranched / Branched	9-15 cm	0.1	2.340	0.860	Inf	2.312	0.021
Unbranched / Branched	16-23 cm	0.1	3.677	1.390	Inf	3.445	0.001
Unbranched / Branched	24-39 cm	0.1	6.284	2.737	Inf	4.219	<0.001
Unbranched / Branched	4-8 cm	0.196	4.437	0.900	Inf	7.345	<0.001
Unbranched / Branched	9-15 cm	0.196	4.335	0.906	Inf	7.015	<0.001
Unbranched / Branched	16-23 cm	0.196	2.860	0.619	Inf	4.853	<0.001
Unbranched / Branched	24-39 cm	0.196	5.898	1.505	Inf	6.956	<0.001
Unbranched / Branched	4-8 cm	0.3	2.268	0.474	Inf	3.918	<0.001

Branchiness comparison	Rubble size	Near-bed wave orbital velocity (m/s)	Odds Ratio	SE	df	z-ratio	p-value
Unbranched / Branched	9-15 cm	0.3	8.433	1.916	Inf	9.383	<0.001
Unbranched / Branched	16-23 cm	0.3	2.181	0.366	Inf	4.654	<0.001
Unbranched / Branched	24-39 cm	0.3	5.508	0.967	Inf	9.722	<0.001
Unbranched / Branched	4-8 cm	0.4	1.188	0.489	Inf	0.419	0.675
Unbranched / Branched	9-15 cm	0.4	16.010	6.482	Inf	6.850	<0.001
Unbranched / Branched	16-23 cm	0.4	1.680	0.513	Inf	1.700	0.089
Unbranched / Branched	24-39 cm	0.4	5.156	1.599	Inf	5.289	<0.001

Table S11 Pairwise comparisons between four categories of rubble 'length' for each level of morphology and 4 levels of continuous variable 'velocity' (0.1 m/s, 0.2 m/s (mean), 0.3 m/s, and 0.4 m/s) for model described in Table S6.

Size comparison	Rubble branchiness	Near-bed wave orbital velocity (m/s)	Odds Ratio	SE	df	z-ratio	p-value
4-8 cm / 9-15 cm	Unbranched	0.1	0.734	0.277	Inf	-0.819	0.846
4-8 cm / 16-23 cm	Unbranched	0.1	0.713	0.255	Inf	-0.946	0.780
4-8 cm / 24-39 cm	Unbranched	0.1	0.871	0.313	Inf	-0.385	0.981
9-15 cm / 16-23 cm	Unbranched	0.1	0.972	0.417	Inf	-0.066	0.999
9-15 cm / 24-39 cm	Unbranched	0.1	1.186	0.511	Inf	0.396	0.979
16-23 cm / 24-39 cm	Unbranched	0.1	1.221	0.504	Inf	0.482	0.963
4-8 cm / 9-15 cm	Branched	0.1	0.208	0.090	Inf	-3.622	0.002
4-8 cm / 16-23 cm	Branched	0.1	0.317	0.149	Inf	-2.453	0.068
4-8 cm / 24-39 cm	Branched	0.1	0.662	0.336	Inf	-0.812	0.849
9-15 cm / 16-23 cm	Branched	0.1	1.528	0.588	Inf	1.101	0.689
9-15 cm / 24-39 cm	Branched	0.1	3.186	1.380	Inf	2.675	0.038

Size comparison	Rubble branchiness	Near-bed wave orbital velocity (m/s)	Odds Ratio	SE	df	z-ratio	p-value
16-23 cm / 24-39 cm	Branched	0.1	2.086	0.975	Inf	1.573	0.394
4-8 cm / 9-15 cm	Unbranched	0.196	0.995	0.205	Inf	-0.025	0.999
4-8 cm / 16-23 cm	Unbranched	0.196	1.684	0.330	Inf	2.659	0.039
4-8 cm / 24-39 cm	Unbranched	0.196	1.983	0.394	Inf	3.442	0.003
9-15 cm / 16-23 cm	Unbranched	0.196	1.693	0.406	Inf	2.197	0.124
9-15 cm / 24-39 cm	Unbranched	0.196	1.993	0.485	Inf	2.835	0.024
16-23 cm / 24-39 cm	Unbranched	0.196	1.177	0.276	Inf	0.694	0.900
4-8 cm / 9-15 cm	Branched	0.196	0.972	0.221	Inf	-0.125	0.999
4-8 cm / 16-23 cm	Branched	0.196	1.086	0.267	Inf	0.336	0.987
4-8 cm / 24-39 cm	Branched	0.196	2.635	0.735	Inf	3.474	0.003
9-15 cm / 16-23 cm	Branched	0.196	1.117	0.245	Inf	0.507	0.958
9-15 cm / 24-39 cm	Branched	0.196	2.711	0.695	Inf	3.893	0.001
16-23 cm / 24-39 cm	Branched	0.196	2.427	0.662	Inf	3.249	0.006
4-8 cm / 9-15 cm	Unbranched	0.3	1.381	0.368	Inf	1.211	0.620
4-8 cm / 16-23 cm	Unbranched	0.3	4.257	0.916	Inf	6.734	<0.001
4-8 cm / 24-39 cm	Unbranched	0.3	4.818	1.066	Inf	7.109	<0.001
9-15 cm / 16-23 cm	Unbranched	0.3	3.082	0.776	Inf	4.470	<0.001
9-15 cm / 24-39 cm	Unbranched	0.3	3.488	0.898	Inf	4.852	<0.001
16-23 cm / 24-39 cm	Unbranched	0.3	1.132	0.226	Inf	0.618	0.926
4-8 cm / 9-15 cm	Branched	0.3	5.136	0.899	Inf	9.348	<0.001
4-8 cm / 16-23 cm	Branched	0.3	4.094	0.734	Inf	7.866	<0.001
4-8 cm / 24-39 cm	Branched	0.3	11.699	2.159	Inf	13.329	<0.001
9-15 cm / 16-23 cm	Branched	0.3	0.797	0.103	Inf	-1.753	0.297
9-15 cm / 24-39 cm	Branched	0.3	2.278	0.311	Inf	6.022	<0.001

Size comparison	Rubble branchiness	Near-bed wave orbital velocity (m/s)	Odds Ratio	SE	df	z-ratio	p-value
16-23 cm / 24-39 cm	Branched	0.3	2.857	0.406	Inf	7.389	<0.001
4-8 cm / 9-15 cm	Unbranched	0.4	1.895	0.916	Inf	1.322	0.549
4-8 cm / 16-23 cm	Unbranched	0.4	10.400	4.104	Inf	5.935	<0.001
4-8 cm / 24-39 cm	Unbranched	0.4	11.333	4.562	Inf	6.031	<0.001
9-15 cm / 16-23 cm	Unbranched	0.4	5.489	2.509	Inf	3.724	0.001
9-15 cm / 24-39 cm	Unbranched	0.4	5.981	2.768	Inf	3.864	0.001
16-23 cm / 24-39 cm	Unbranched	0.4	1.090	0.397	Inf	0.235	0.995
4-8 cm / 9-15 cm	Branched	0.4	25.529	9.372	Inf	8.825	<0.001
4-8 cm / 16-23 cm	Branched	0.4	14.704	5.606	Inf	7.051	<0.001
4-8 cm / 24-39 cm	Branched	0.4	49.175	18.392	Inf	10.415	<0.001
9-15 cm / 16-23 cm	Branched	0.4	0.576	0.144	Inf	-2.214	0.120
9-15 cm / 24-39 cm	Branched	0.4	1.926	0.458	Inf	2.755	0.030
16-23 cm / 24-39 cm	Branched	0.4	3.344	0.867	Inf	4.659	<0.001

Table S12 Pairwise comparisons between sand and rubble substrate for each level of 'size' and 4 levels of continuous variable 'velocity' (0.1 m/s, 0.2 m/s (mean), 0.3 m/s and 0.4 m/s) for model described in Table S6.

Substrate comparison	Rubble size	Near-bed wave orbital velocity (m/s)	Odds Ratio	SE	df	z-ratio	p-value
Rubble / Sand	4-8 cm	0.1	2.011	0.764	Inf	1.840	0.066
Rubble / Sand	9-15 cm	0.1	1.092	0.447	Inf	0.215	0.830
Rubble / Sand	16-23 cm	0.1	1.728	0.787	Inf	1.200	0.230
Rubble / Sand	24-39 cm	0.1	1.305	0.630	Inf	0.552	0.581
Rubble / Sand	4-8 cm	0.196	0.879	0.168	Inf	-0.678	0.498
Rubble / Sand	9-15 cm	0.196	0.909	0.216	Inf	-0.402	0.688

Substrate comparison	Rubble size	Near-bed wave orbital velocity (m/s)	Odds Ratio	SE	df	z-ratio	p-value
Rubble / Sand	16-23 cm	0.196	1.100	0.281	Inf	0.372	0.710
Rubble / Sand	24-39 cm	0.196	1.452	0.410	Inf	1.321	0.187
Rubble / Sand	4-8 cm	0.3	0.359	0.087	Inf	-4.224	<0.001
Rubble / Sand	9-15 cm	0.3	0.746	0.130	Inf	-1.688	0.091
Rubble / Sand	16-23 cm	0.3	0.675	0.110	Inf	-2.419	0.016
Rubble / Sand	24-39 cm	0.3	1.629	0.270	Inf	2.949	0.003
Rubble / Sand	4-8 cm	0.4	0.152	0.071	Inf	-4.051	<0.001
Rubble / Sand	9-15 cm	0.4	0.616	0.192	Inf	-1.553	0.121
Rubble / Sand	16-23 cm	0.4	0.422	0.135	Inf	-2.705	0.007
Rubble / Sand	24-39 cm	0.4	1.820	0.539	Inf	2.021	0.043
Rubble / Sand	4-8 cm	0.1	2.011	0.764	Inf	1.840	0.066
Rubble / Sand	9-15 cm	0.1	1.092	0.447	Inf	0.215	0.830
Rubble / Sand	16-23 cm	0.1	1.728	0.787	Inf	1.200	0.230
Rubble / Sand	24-39 cm	0.1	1.305	0.630	Inf	0.552	0.581
Rubble / Sand	4-8 cm	0.196	0.879	0.168	Inf	-0.678	0.498
Rubble / Sand	9-15 cm	0.196	0.909	0.216	Inf	-0.402	0.688
Rubble / Sand	16-23 cm	0.196	1.100	0.281	Inf	0.372	0.710
Rubble / Sand	24-39 cm	0.196	1.452	0.410	Inf	1.321	0.187
Rubble / Sand	4-8 cm	0.3	0.359	0.087	Inf	-4.224	<0.001
Rubble / Sand	9-15 cm	0.3	0.746	0.130	Inf	-1.688	0.091
Rubble / Sand	16-23 cm	0.3	0.675	0.110	Inf	-2.419	0.016
Rubble / Sand	24-39 cm	0.3	1.629	0.270	Inf	2.949	0.003
Rubble / Sand	4-8 cm	0.4	0.152	0.071	Inf	-4.051	<0.001
Rubble / Sand	9-15 cm	0.4	0.616	0.192	Inf	-1.553	0.121

Substrate comparison	Rubble size	Near-bed wave orbital velocity (m/s)	Odds Ratio	SE	df	z-ratio	p-value
Rubble / Sand	16-23 cm	0.4	0.422	0.135	Inf	-2.705	0.007
Rubble / Sand	24-39 cm	0.4	1.820	0.539	Inf	2.021	0.043

Table S13 Anova table of model "fl.f.global2" describing the effect of velocity, rubble size, branchiness and underlying substrate on the probability of flipping of rubble pieces.

Model term	LR χ^2	Df	Pr(>χ^2)
calculated.velocity_corrected	1550.877	1	<0.001
size	323.197	3	<0.001
substrate	7.253	1	0.007
branched	533.511	1	<0.001
calculated.velocity_corrected:size	59.299	3	<0.001
calculated.velocity_corrected:substrate	1.919	1	0.166
calculated.velocity_corrected:branched	1.003	1	0.317
size:substrate	21.392	3	<0.001
size:branched	34.631	3	<0.001
substrate:branched	19.138	1	<0.001
calculated.velocity_corrected:size:branched	18.363	3	<0.001
calculated.velocity_corrected:size:substrate	10.738	3	0.013

Table S14 Pairwise comparisons branched and unbranched rubble for each level of 'size' and 3 levels of continuous variable 'velocity' (0.1 m/s, 0.2 m/s (mean) and 0.4 m/s) for model described in Table S10.

Branchiness comparison	Rubble size	Near-bed wave orbital velocity (m/s)	Odds Ratio	SE	df	z-ratio	p-value
Unbranched / Branched	4-8 cm	0.1	10.977	4.530	Inf	5.805	<0.001
Unbranched / Branched	9-15 cm	0.1	3.241	1.273	Inf	2.995	0.003
Unbranched / Branched	16-23 cm	0.1	5.403	2.237	Inf	4.074	<0.001
Unbranched / Branched	24-39 cm	0.1	42.522	32.482	Inf	4.909	<0.001
Unbranched / Branched	4-8 cm	0.196	7.006	1.541	Inf	8.852	<0.001
Unbranched / Branched	9-15 cm	0.196	7.459	1.676	Inf	8.943	<0.001
Unbranched / Branched	16-23 cm	0.196	5.656	1.373	Inf	7.136	<0.001
Unbranched / Branched	24-39 cm	0.196	33.922	16.101	Inf	7.425	<0.001
Unbranched / Branched	4-8 cm	0.4	2.706	1.073	Inf	2.512	0.012
Unbranched / Branched	9-15 cm	0.4	43.609	17.966	Inf	9.164	<0.001
Unbranched / Branched	16-23 cm	0.4	6.233	1.965	Inf	5.805	<0.001
Unbranched / Branched	24-39 cm	0.4	21.016	8.938	Inf	7.161	<0.001
Unbranched / Branched	4-8 cm	0.1	10.977	4.530	Inf	5.805	<0.001
Unbranched / Branched	9-15 cm	0.1	3.241	1.273	Inf	2.995	0.003
Unbranched / Branched	16-23 cm	0.1	5.403	2.237	Inf	4.074	<0.001
Unbranched / Branched	24-39 cm	0.1	42.522	32.482	Inf	4.909	<0.001
Unbranched / Branched	4-8 cm	0.196	7.006	1.541	Inf	8.852	<0.001
Unbranched / Branched	9-15 cm	0.196	7.459	1.676	Inf	8.943	<0.001
Unbranched / Branched	16-23 cm	0.196	5.656	1.373	Inf	7.136	<0.001
Unbranched / Branched	24-39 cm	0.196	33.922	16.101	Inf	7.425	<0.001
Unbranched / Branched	4-8 cm	0.4	2.706	1.073	Inf	2.512	0.012
Unbranched / Branched	9-15 cm	0.4	43.609	17.966	Inf	9.164	<0.001
Unbranched / Branched	16-23 cm	0.4	6.233	1.965	Inf	5.805	<0.001
Unbranched / Branched	24-39 cm	0.4	21.016	8.938	Inf	7.161	<0.001

Table S15 Pairwise comparisons between rubble size categories for each level of 'morphology' and 3 levels of continuous variable 'velocity' (0.1 m/s, 0.2 m/s (mean) and 0.4 m/s) for model described in Table S10.

Size comparison	Rubble branchiness	Near-bed wave orbital velocity (m/s)	Odds Ratio	SE	df	z-ratio	p-value
4-8 cm / 9-15 cm	Unbranched	0.1	0.741	0.279	Inf	-0.796	0.857
4-8 cm / 16-23 cm	Unbranched	0.1	0.662	0.228	Inf	-1.198	0.628
4-8 cm / 24-39 cm	Unbranched	0.1	0.965	0.366	Inf	-0.094	0.999
9-15 cm / 16-23 cm	Unbranched	0.1	0.893	0.377	Inf	-0.268	0.993
9-15 cm / 24-39 cm	Unbranched	0.1	1.301	0.588	Inf	0.583	0.937
16-23 cm / 24-39 cm	Unbranched	0.1	1.458	0.622	Inf	0.884	0.813
4-8 cm / 9-15 cm	Branched	0.1	0.219	0.103	Inf	-3.213	0.007
4-8 cm / 16-23 cm	Branched	0.1	0.326	0.168	Inf	-2.181	0.128
4-8 cm / 24-39 cm	Branched	0.1	3.738	3.130	Inf	1.575	0.393
9-15 cm / 16-23 cm	Branched	0.1	1.488	0.670	Inf	0.883	0.814
9-15 cm / 24-39 cm	Branched	0.1	17.072	13.667	Inf	3.544	0.002
16-23 cm / 24-39 cm	Branched	0.1	11.473	9.473	Inf	2.955	0.017
4-8 cm / 9-15 cm	Unbranched	0.196	1.021	0.210	Inf	0.102	0.999
4-8 cm / 16-23 cm	Unbranched	0.196	1.712	0.329	Inf	2.799	0.026
4-8 cm / 24-39 cm	Unbranched	0.196	2.772	0.599	Inf	4.717	<0.001
9-15 cm / 16-23 cm	Unbranched	0.196	1.676	0.400	Inf	2.166	0.133
9-15 cm / 24-39 cm	Unbranched	0.196	2.714	0.703	Inf	3.854	0.001
16-23 cm / 24-39 cm	Unbranched	0.196	1.619	0.401	Inf	1.949	0.208
4-8 cm / 9-15 cm	Branched	0.196	1.087	0.280	Inf	0.325	0.988
4-8 cm / 16-23 cm	Branched	0.196	1.382	0.389	Inf	1.148	0.659
4-8 cm / 24-39 cm	Branched	0.196	13.421	6.755	Inf	5.159	<0.001
9-15 cm / 16-23 cm	Branched	0.196	1.271	0.334	Inf	0.911	0.799

Size comparison	Rubble branchiness	Near-bed wave orbital velocity (m/s)	Odds Ratio	SE	df	z-ratio	p-value
9-15 cm / 24-39 cm	Branched	0.196	12.343	6.099	Inf	5.086	<0.001
16-23 cm / 24-39 cm	Branched	0.196	9.712	4.924	Inf	4.484	<0.001
4-8 cm / 9-15 cm	Unbranched	0.4	2.013	0.955	Inf	1.474	0.453
4-8 cm / 16-23 cm	Unbranched	0.4	12.810	4.888	Inf	6.683	<0.001
4-8 cm / 24-39 cm	Unbranched	0.4	25.924	10.097	Inf	8.358	<0.001
9-15 cm / 16-23 cm	Unbranched	0.4	6.365	2.850	Inf	4.133	<0.001
9-15 cm / 24-39 cm	Unbranched	0.4	12.881	5.826	Inf	5.651	<0.001
16-23 cm / 24-39 cm	Unbranched	0.4	2.024	0.713	Inf	2.002	0.187
4-8 cm / 9-15 cm	Branched	0.4	32.430	11.517	Inf	9.796	<0.001
4-8 cm / 16-23 cm	Branched	0.4	29.505	10.896	Inf	9.165	<0.001
4-8 cm / 24-39 cm	Branched	0.4	201.319	91.599	Inf	11.659	<0.001
9-15 cm / 16-23 cm	Branched	0.4	0.910	0.265	Inf	-0.324	0.988
9-15 cm / 24-39 cm	Branched	0.4	6.208	2.438	Inf	4.650	<0.001
16-23 cm / 24-39 cm	Branched	0.4	6.823	2.766	Inf	4.737	<0.001

76 **Table S16 Pairwise comparisons between rubble and sand substrate for each level of 'morphology' and 3 levels of continuous variable 'velocity' (0.1 m/s, 0.2 m/s (mean) and 0.4 m/s)**
77 **for model described in Table S10.**

Substrate comparison	Rubble size	Near-bed wave orbital velocity (m/s)	Odds Ratio	SE	df	z-ratio	p-value
Rubble / Sand	Unbranched	0.1	1.091	0.267	Inf	0.354	0.723
Rubble / Sand	Branched	0.1	2.710	0.840	Inf	3.216	0.001
Rubble / Sand	Unbranched	0.196	0.949	0.148	Inf	-0.334	0.738
Rubble / Sand	Branched	0.196	2.358	0.481	Inf	4.208	<0.001
Rubble / Sand	Unbranched	0.4	0.708	0.176	Inf	-1.388	0.165

Substrate comparison	Rubble size	Near-bed wave orbital velocity (m/s)	Odds Ratio	SE	df	z-ratio	p-value
Rubble / Sand	Branched	0.4	1.758	0.352	Inf	2.815	0.005
Rubble / Sand	Unbranched	0.1	1.091	0.267	Inf	0.354	0.723
Rubble / Sand	Branched	0.1	2.710	0.840	Inf	3.216	0.001
Rubble / Sand	Unbranched	0.196	0.949	0.148	Inf	-0.334	0.738
Rubble / Sand	Branched	0.196	2.358	0.481	Inf	4.208	<0.001
Rubble / Sand	Unbranched	0.4	0.708	0.176	Inf	-1.388	0.165
Rubble / Sand	Branched	0.4	1.758	0.352	Inf	2.815	0.005

78 **Table S17 Anova table of model "lockmove2" and Anova table of model "lockflip".**

	LR χ^2	Df	Pr(>χ^2)
Transport			
calculated.velocity_corrected	1.036	1	0.309
size	2.571	1	0.109
calculated.velocity_corrected:size	2.146	1	0.143
Flipping			
calculated.velocity_corrected	1.626	1	0.202
size	2.152	1	0.142
calculated.velocity_corrected:size	9.3E-09	1	0.999

79 **Table S18 The min, max and median recorded fastest near-bed wave orbital velocities in each habitat and monsoon season.**

Monsoon season	Habitat	Peak near-bed wave orbital velocity (m/s)		
		Min	Median	Max
North-eastern	Lagoon	0.0847	0.163	0.217
	Sheltered Shallow	0.0812	0.0977	0.224
	Sheltered Deep	0.0439	0.0524	0.0857
	Exposed Shallow	0.0501	0.13	0.215
	Exposed Deep	0.00868	0.0252	0.0324
Western	Lagoon	0.211	0.242	0.293
	Sheltered Shallow	0.11	0.266	0.398
	Sheltered Deep	0.0583	0.129	0.185
	Exposed Shallow	0.114	0.184	0.429
	Exposed Deep	0.0603	0.0984	0.168

Table S19 Anova table of model "gamma1".

Model term	χ^2	Df	Pr(>χ^2)
aspectDepth	533.057	4.000	<0.001
season	18.961	1.000	<0.001
aspectDepth:season	54.204	4.000	<0.001

Table S20 Pairwise comparisons between two monsoon seasons (W and NE monsoon) for 5 levels of 'habitat' (i.e, Lagoon shallow, Sheltered Shallow, Sheltered Deep, Exposed Shallow, Exposed Deep) for model "gamma1".

Monsoon comparison	Habitat	Odds Ratio	SE	df	z-ratio	p-value
NE Monsoon / W Monsoon	Lag_Shal	0.604	0.212	Inf	-1.433	0.152

NE Monsoon / W Monsoon	Shelt_Shal	0.434	0.110	Inf	-3.297	0.001
NE Monsoon / W Monsoon	Shelt_Deep	0.480	0.121	Inf	-2.903	0.004
NE Monsoon / W Monsoon	Exp_Shal	0.663	0.191	Inf	-1.424	0.154
NE Monsoon / W Monsoon	Exp_Deep	0.322	0.093	Inf	-3.918	<0.001

Table S21 Pairwise comparisons for 5 levels of 'habitat' (i.e, Lagoon shallow, Sheltered Shallow, Sheltered Deep, Exposed Shallow, Exposed Deep) in each of two monsoon seasons (W and NE monsoon) for model "gamma1".

Habitat comparison	Monsoon	Odds Ratio	SE	df	z-ratio	p-value
Lag_Shal / Shelt_Shal	NE Monsoon	1.343	0.410	Inf	0.966	0.871
Lag_Shal / Shelt_Deep	NE Monsoon	2.462	0.751	Inf	2.953	0.026
Lag_Shal / Exp_Shal	NE Monsoon	1.102	0.355	Inf	0.302	0.998
Lag_Shal / Exp_Deep	NE Monsoon	4.046	1.301	Inf	4.345	<0.001
Shelt_Shal / Shelt_Deep	NE Monsoon	1.834	0.113	Inf	9.866	<0.001
Shelt_Shal / Exp_Shal	NE Monsoon	0.821	0.222	Inf	-0.730	0.950
Shelt_Shal / Exp_Deep	NE Monsoon	3.013	0.815	Inf	4.080	<0.001
Shelt_Deep / Exp_Shal	NE Monsoon	0.448	0.121	Inf	-2.973	0.025
Shelt_Deep / Exp_Deep	NE Monsoon	1.643	0.444	Inf	1.837	0.352
Exp_Shal / Exp_Deep	NE Monsoon	3.671	0.257	Inf	18.543	<0.001
Lag_Shal / Shelt_Shal	W Monsoon	0.965	0.296	Inf	-0.117	1.000
Lag_Shal / Shelt_Deep	W Monsoon	1.954	0.600	Inf	2.182	0.187
Lag_Shal / Exp_Shal	W Monsoon	1.208	0.389	Inf	0.588	0.977
Lag_Shal / Exp_Deep	W Monsoon	2.158	0.694	Inf	2.391	0.118
Shelt_Shal / Shelt_Deep	W Monsoon	2.026	0.171	Inf	8.342	<0.001
Shelt_Shal / Exp_Shal	W Monsoon	1.253	0.342	Inf	0.825	0.923

Habitat comparison	Monsoon	Odds Ratio	SE	df	z-ratio	p-value
Shelt_Shal / Exp_Deep	W Monsoon	2.237	0.610	Inf	2.951	0.026
Shelt_Deep / Exp_Shal	W Monsoon	0.618	0.169	Inf	-1.763-	0.396
Shelt_Deep / Exp_Deep	W Monsoon	1.104	0.301	Inf	0.363	0.996
Exp_Shal / Exp_Deep	W Monsoon	1.786	0.125	Inf	8.270	<0.001

86

87 **Table S22 Anova table for model "wmod".**

Model term	$\chi 2$	Df	Pr(>$\chi 2$)
fastest_peak_U	10.434	1.000	0.001
day2	129.258	2.000	<0.001
fastest_peak_U:day2	11.284	2.000	0.004

88 **Table S23 Anova table for model "wmod.fl".**

Model term	X2	Df	Pr(>X2)
fastest_peak_U	11.869	1.000	0.001
day2	57.711	2.000	0.000
fastest_peak_U:day2	7.416	2.000	0.025

89

90 **Table S24 Model predictions for probability of transport on each day in the western monsoon at 4 different velocities: 0.1, 0.2, 0.3 and 0.4 m/s, for model "wmod".**

Velocity	Day	Probability of transport	SE	df	Lower confidence interval	Upper confidence interval
0.1	One	0.301	0.038	Inf	0.233	0.380
0.2	One	0.392	0.035	Inf	0.326	0.463
0.3	One	0.491	0.043	Inf	0.408	0.574
0.4	One	0.591	0.057	Inf	0.477	0.696
0.1	Two	0.208	0.032	Inf	0.152	0.278
0.2	Two	0.205	0.026	Inf	0.159	0.260
0.3	Two	0.201	0.034	Inf	0.143	0.275
0.4	Two	0.197	0.049	Inf	0.118	0.310
0.1	Three	0.091	0.019	Inf	0.060	0.136
0.2	Three	0.113	0.018	Inf	0.083	0.153
0.3	Three	0.140	0.030	Inf	0.091	0.209
0.4	Three	0.172	0.054	Inf	0.090	0.303

91 **Table S25 Pairwise comparisons between each level of day, at three levels of velocity for model "wmod.fl".**

Velocity	Day	Probability of transport	SE	df	Lower confidence interval	Upper confidence interval
0.1	One	0.125	0.021	Inf	0.089	0.172
0.2	One	0.183	0.021	Inf	0.146	0.228
0.3	One	0.261	0.031	Inf	0.204	0.327
0.4	One	0.357	0.055	Inf	0.257	0.470
0.1	Two	0.091	0.018	Inf	0.061	0.133

Velocity	Day	Probability of transport	SE	df	Lower confidence interval	Upper confidence interval
0.2	Two	0.091	0.014	Inf	0.067	0.123
0.3	Two	0.091	0.022	Inf	0.057	0.143
0.4	Two	0.092	0.034	Inf	0.044	0.182
0.1	Three	0.043	0.011	Inf	0.025	0.072
0.2	Three	0.055	0.010	Inf	0.038	0.079
0.3	Three	0.070	0.020	Inf	0.039	0.123
0.4	Three	0.090	0.041	Inf	0.035	0.208

92 **Table S26 Anova table for model "wmod.dist2".**

Model term	X2	Df	Pr(>X2)
fastest_peak_U	7.110	1.000	0.008
day2	17.275	2.000	<0.001

93 **Table S27 Model predictions for distance of transport, and pairwise comparisons between each level of day, at the average velocity in the western monsoon for model described in**
94 **"wmod.dist2".**

Day	Distance transported	SE	df	Lower confidence interval	Upper confidence interval
One	5.367	0.387	14.000	4.598	6.265
Two	3.850	0.322	14.000	3.217	4.607
Three	4.601	0.468	14.000	3.699	5.723
Day comparison	**Odds Ratio**	**SE**	**df**	**z-ratio**	**p-value**
One - Two	1.394	0.112	526.000	4.133	<0.001
One - Three	1.167	0.115	526.000	1.560	0.264
Two - Three	0.837	0.088	526.000	-1.688	0.211

Table S28 Anova table for model "nemod2".

	χ2	Df	Pr(>χ2)
fastest_peak_U	2.270	1.000	0.132
day2	7.304	2.000	0.026

Table S29 Anova table for model "nemod.fl2".

Model term	X2	Df	Pr(>X2)
fastest_peak_U	3.727	1.000	0.054
day2	28.091	2.000	<0.001

Table S30 Pairwise comparisons between each level of day, at the average velocity (0.2 m/s) for model "nemod2".

Day	Probability of transport	SE	df	Lower confidence interval	Upper confidence interval
One	0.217	0.021	Inf	0.179	0.260
Two	0.202	0.020	Inf	0.165	0.243
Three	0.157	0.018	Inf	0.126	0.195
Day comparison	**Odds Ratio**	**SE**	**df**	**z-ratio**	**p-value**
One - Two	1.097	0.160	Inf	0.635	0.801
One - Three	1.484	0.224	Inf	2.612	0.024
Two - Three	1.353	0.206	Inf	1.988	0.115

Table S31 Model predictions for probability of flipping on each day in the north-eastern monsoon, and pairwise comparisons between each level of day, at the average velocity for model "nemod.fl2".

Day	Probability of transport	SE	df	Lower confidence interval	Upper confidence interval
One	0.131	0.018	Inf	0.100	0.171
Two	0.063	0.012	Inf	0.043	0.090
Three	0.061	0.011	Inf	0.042	0.087
Day comparison	**Odds Ratio**	**SE**	**df**	**z-ratio**	**p-value**
One - Two	2.269	0.427	Inf	4.350	<0.001
One - Three	2.347	0.446	Inf	4.489	<0.001
Two - Three	1.035	0.216	Inf	0.163	0.986

Table S32 Anova table for model "nemod.dist2".

	χ2	Df	Pr(>χ2)
fastest_peak_U	5.971	1.000	0.015
day2	16.293	2.000	<0.001

Table S33 Model predictions and pairwise comparisons between each level of day for the average velocity for model "nemod.dist2".

Day	Distance transported	SE	df	Lower confidence interval	Upper confidence interval
One	4.771	0.316	14	4.139	5.499
Two	4.030	0.272	14	3.488	4.657
Three	3.448	0.249	14	2.952	4.026
Day comparison	**Odds Ratio**	**SE**	**df**	**z-ratio**	**p-value**
One - Two	1.184	0.091	397	2.186	0.075

One - Three	1.384	0.112	397	3.997	<0.001
Two - Three	1.169	0.097	397	1.889	0.143

Table S34 Model (ldmod) used for predictions of velocity thresholds for transport (sliding/walking/flipping) of 10%, 50% and 90% of rubble pieces averaged across different sizes, branchiness and substrate categories.

Model term	χ^2	Df	Pr(>χ^2)
fastest_peak_U	33.468	1	<0.001

Table S35 Anova table of model "fi.m.senglob5".

Model term	X2	Df	Pr(>X2)
fastest_peak_U	32.624	1.000	<0.001
size_cat_adjusted_to_flume_exp	35.514	2.000	<0.001
branched	17.643	1.000	<0.001
starting_substrate_new	0.438	2.000	0.803
fastest_peak_U:size_cat_adjusted_to_flume_exp	10.039	2.000	0.007

Table S36 Pairwise comparisons between three different rubble size categories and 8 levels of continuous variable 'velocity' (0.03 m/s, 0.1 m/s, 0.17 m/s (mean), 0.19 m/s, 0.25 m/s, 0.3 m/s, 0.4 m/s, 0.55 for model described in Table S35.

Size comparison	Velocity (m/s)	Odds Ratio	SE	df	z-ratio	p-value
4-8cm / 9-15cm	0.011	2.469	0.558	Inf	4.001	<0.001
4-8cm / 16-23cm	0.011	7.151	2.563	Inf	5.489	<0.001
9-15cm / 16-23cm	0.011	2.897	1.026	Inf	3.002	0.008

Size comparison	Velocity (m/s)	Odds Ratio	SE	df	z-ratio	p-value
4-8cm / 9-15cm	0.100	2.038	0.306	Inf	4.733	<0.001
4-8cm / 16-23cm	0.100	4.344	1.053	Inf	6.060	<0.001
9-15cm / 16-23cm	0.100	2.132	0.512	Inf	3.153	0.005
4-8cm / 9-15cm	0.153	1.820	0.243	Inf	4.481	<0.001
4-8cm / 16-23cm	0.153	3.240	0.660	Inf	5.767	<0.001
9-15cm / 16-23cm	0.153	1.780	0.358	Inf	2.866	0.012
4-8cm / 9-15cm	0.190	1.680	0.237	Inf	3.682	0.001
4-8cm / 16-23cm	0.190	2.632	0.527	Inf	4.836	<0.001
9-15cm / 16-23cm	0.190	1.567	0.308	Inf	2.286	0.058
4-8cm / 9-15cm	0.250	1.477	0.266	Inf	2.168	0.077
4-8cm / 16-23cm	0.250	1.884	0.447	Inf	2.673	0.021
9-15cm / 16-23cm	0.250	1.276	0.294	Inf	1.055	0.542
4-8cm / 9-15cm	0.300	1.327	0.302	Inf	1.246	0.426
4-8cm / 16-23cm	0.300	1.426	0.421	Inf	1.203	0.451
9-15cm / 16-23cm	0.300	1.075	0.308	Inf	0.252	0.966
4-8cm / 9-15cm	0.400	1.071	0.362	Inf	0.203	0.978
4-8cm / 16-23cm	0.400	0.817	0.362	Inf	-0.455	0.892
9-15cm / 16-23cm	0.400	0.763	0.329	Inf	-0.627	0.805
4-8cm / 9-15cm	0.429	1.006	0.374	Inf	0.016	1.000
4-8cm / 16-23cm	0.429	0.694	0.341	Inf	-0.743	0.738
9-15cm / 16-23cm	0.429	0.690	0.329	Inf	-0.777	0.717

Table S37 Model predictions and pairwise comparisons between branched and unbranched rubble (averaged across velocity because there was no interaction between velocity and branchiness) for model described in Table S35.

Branchiness	Distance transported	SE	df	Lower confidence interval	Upper confidence interval
Unbranched	0.369	0.040	Inf	0.294	0.451
Branched	0.256	0.031	Inf	0.200	0.322
Branchiness comparison	**Odds Ratio**	**SE**	**df**	**z-ratio**	**p-value**
Unbranched / Branched	1.703	0.216	Inf	4.200	<0.000

Table S38 Anova table for model "compnewSLONLY".

Model term	X2	Df	Pr(>X2)
fastest_peak_U	45.510	1.000	<0.001
avg_slope_angle_transect.1	13.851	1.000	<0.001
fastest_peak_U:avg_slope_angle_transect.1	5.585	1.000	0.018

Table S39 Pairwise comparisons between three different slope categories and 4 levels of continuous variable 'velocity' (0.1 m/s, 0.2 m/s (mean), 0.3 m/s, 0.4 m/s, for model "compnewSLONLY".

Slope angle	Velocity	Probability of transport	SE	df	Lower confidence interval	Upper confidence interval
3	0.1	0.161	0.027	Inf	0.115	0.220
13	0.1	0.241	0.021	Inf	0.202	0.285
22	0.1	0.334	0.026	Inf	0.285	0.388
3	0.2	0.302	0.032	Inf	0.243	0.369
13	0.2	0.343	0.025	Inf	0.296	0.393

22	0.2	0.381	0.045	Inf	0.298	0.471
3	0.3	0.495	0.059	Inf	0.383	0.608
13	0.3	0.461	0.036	Inf	0.390	0.532
22	0.3	0.430	0.077	Inf	0.289	0.583
3	0.4	0.690	0.078	Inf	0.520	0.820
13	0.4	0.583	0.050	Inf	0.484	0.676
22	0.4	0.480	0.113	Inf	0.275	0.692

Slope comparison	**Velocity (m/s)**	**Odds Ratio**	**SE**	**df**	**z-ratio**	**p-value**
3 / 13	0.1	0.602	0.070	Inf	-4.353	<0.001
3 / 22	0.1	0.381	0.084	Inf	-4.353	<0.001
13 / 22	0.1	0.633	0.066	Inf	-4.353	<0.001
3 / 13	0.2	0.832	0.117	Inf	-1.313	0.388
3 / 22	0.2	0.704	0.188	Inf	-1.313	0.388
13 / 22	0.2	0.847	0.107	Inf	-1.313	0.388
3 / 13	0.3	1.149	0.289	Inf	0.552	0.845
3 / 22	0.3	1.302	0.622	Inf	0.552	0.845
13 / 22	0.3	1.133	0.256	Inf	0.552	0.845
3 / 13	0.4	1.350	0.3473	1312	1.166	0.474
3 / 22	0.4	1.768	0.8645	1312	1.166	0.474
13 / 22	0.4	1.310	0.3034	1312	1.166	0.474

Table S40 Anova table of model “fi.f.senglob5”.

Model term	**X2**	**Df**	**Pr(>X2)**

fastest_peak_U	8.178	1.000	0.004
size_cat_adjusted_to_flume_exp	40.585	2.000	<0.001
branched	28.154	1.000	<0.001
starting_substrate_new	4.989	2.000	0.083
fastest_peak_U:size_cat_adjusted_to_flume_exp	7.019	2.000	0.030
size_cat_adjusted_to_flume_exp:branched	8.335	2.000	0.015

117 **Table S41 Pairwise comparisons between branched and unbranched rubble for each level of 'size' (4-8 cm, 9-15 cm, 16-23 cm) for model "fi.f.senglob5".**

Branchiness contrast	Velocity (m/s)	Odds Ratio	SE	df	z-ratio	p-value
Unbranched / Branched	4-8cm	1.794	0.382	Inf	2.745	0.006
Unbranched / Branched	9-15cm	3.833	0.958	Inf	5.377	<0.001
Unbranched / Branched	16-23cm	1.148	0.475	Inf	0.334	0.738

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119 **Table S42 Pairwise comparisons between three different rubble size categories for each level of 'branched' (branched and unbranched) for model "fi.f.senglob5".**

Size comparison	Branchiness	Odds Ratio	SE	df	z-ratio	p-value
4-8cm / 9-15cm	Unbranched	1.860	0.417	Inf	2.766	0.016
4-8cm / 16-23cm	Unbranched	4.244	1.623	Inf	3.781	<0.001
9-15cm / 16-23cm	Unbranched	2.282	0.865	Inf	2.177	0.075
4-8cm / 9-15cm	Branched	3.973	0.955	Inf	5.742	<0.001
4-8cm / 16-23cm	Branched	2.716	0.789	Inf	3.438	0.002
9-15cm / 16-23cm	Branched	0.684	0.220	Inf	-1.182	0.464

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Table S43 Pairwise comparisons between three different rubble size categories and 8 levels of continuous variable 'velocity' (0.03 m/s, 0.1 m/s, 0.17 m/s (mean), 0.19 m/s, 0.25 m/s, 0.3 m/s, 0.4 m/s, 0.55 for model described in Table S37 ("fi.f.senglob5").

Size comparison	Velocity (m/s)	Odds Ratio	SE	df	z-ratio	p-value
4-8cm / 9-15cm	0.100	3.116	0.586	Inf	6.038	<0.001
4-8cm / 16-23cm	0.100	4.306	1.256	Inf	5.004	<0.001
9-15cm / 16-23cm	0.100	1.382	0.418	Inf	1.069	0.533
4-8cm / 9-15cm	0.200	2.405	0.411	Inf	5.136	<0.001
4-8cm / 16-23cm	0.200	2.743	0.650	Inf	4.259	<0.001
9-15cm / 16-23cm	0.200	1.140	0.276	Inf	0.542	0.850
4-8cm / 9-15cm	0.300	1.857	0.467	Inf	2.463	0.037
4-8cm / 16-23cm	0.300	1.747	0.539	Inf	1.807	0.167
9-15cm / 16-23cm	0.300	0.941	0.292	Inf	-0.196	0.979
4-8cm / 9-15cm	0.400	1.433	0.531	Inf	0.972	0.595
4-8cm / 16-23cm	0.400	1.112	0.501	Inf	0.237	0.970
9-15cm / 16-23cm	0.400	0.776	0.352	Inf	-0.559	0.842

Table S44 Anova table of model "flip.compnewSLONLY".

Model term	X2	Df	Pr(>X2)
fastest_peak_U	7.197	1	0.007
avg_slope_angle_transect.1	0.384	1	0.536
fastest_peak_U:avg_slope_angle_transect.1	0.619	1	0.431

Table S45 Anova table of model "fi.d.add2".

Model term	X2	Df	Pr(>X2)
fastest_peak_U	12.269	1	<0.001
size_cat_adjusted_to_flume_exp	3.666	2	0.1599
branched	0.503	1	0.478
starting_substrate_new	6.152	2	0.046

Table S46 Pairwise comparisons between three different substrate categories (hard carbonate, rubble and sand) for model "fi.d.add2".

Substrate contrast	Odds Ratio	SE	df	t-ratio	p-value
Hard carbonate / Rubble	1.133	0.141	425.000	1.006	0.574
Hard carbonate / Sand	0.870	0.137	425.000	-0.882	0.652
Rubble / Sand	0.768	0.087	425.000	-2.346	0.051

Table S47 Anova table of model "fi.d.sl2".

Model term	X2	Df	Pr(>X2)
fastest_peak_U	17.271	1.000	<0.001
avg_slope_angle_transect.1	7.873	1.000	0.005
fastest_peak_U:avg_slope_angle_transect.1	26.204	1.000	<0.001

Table S48 Predictions for distance of transport for three examples of slope angle, very gentle (3 degrees), moderate (13 degrees) and very strong (22 degrees) for model in Table S43.

Slope angle	Velocity	Distance transported	SE	df	Lower confidence interval	Upper confidence interval

3	0.1	2.989	0.244	Inf	2.575	3.551
13	0.1	3.790	0.215	Inf	3.406	4.257
22	0.1	4.902	0.331	Inf	4.318	5.628
3	0.2	4.732	0.418	Inf	4.017	5.682
13	0.2	4.366	0.247	Inf	3.923	4.899
22	0.2	4.075	0.393	Inf	3.415	4.988
3	0.3	9.082	1.656	Inf	6.530	13.387
13	0.3	5.105	0.398	Inf	4.411	5.993
22	0.3	3.461	0.482	Inf	2.709	4.696
3	0.4	22.918	9.184	Inf	11.441	55.960
13	0.4	6.069	0.715	Inf	4.886	7.765
22	0.4	2.996	0.524	Inf	2.231	4.481

Table S49 Anova table of model “probmove”.

Model term	χ^2	Df	Pr(>χ^2)
MovementType	33.6712023	2	<0.001