APPENDIX A

Table A.1 lists laboratory ice rubble shear data from literature sources referred to in Subsection 4.2.4 - ice rubble regression analysis.

Table A.1 Ice rubble shear data from literature sources.

Auth/Ref	**Ice block Min L** Li m	**Median of Max L** Lx m	**Shear Speed** V m/s	**Ice block Flex** σfl Pa	**Pore fluid Sal./impur.** S % wt	**Bulk Porosity** e %	**Buoyant Weight** γ N/m^3	**Stress Normal** σn Pa	**Stress Shear** τ Pa
Keinonan & Nyman (1978)	0.02	0.064	0.025	15000	0.6	35	670	475	475
	0.02	0.064	0.025	15000	0.6	35	670	475	500
	0.02	0.064	0.025	15000	0.6	35	670	475	505
	0.02	0.064	0.025	15000	0.6	35	670	475	605
	0.02	0.064	0.025	15000	0.6	35	670	1375	1375
	0.02	0.064	0.025	15000	0.6	35	670	1375	1425
	0.02	0.064	0.025	15000	0.6	35	670	1375	1580
	0.02	0.064	0.025	15000	0.6	35	670	1375	1580
Prodanovic (1979)	0.019	0.152	0.000106	19500	5.5	37.5	736	55.9	270
	0.019	0.076	0.000106	19500	5.5	37.5	736	55.9	290
	0.019	0.152	0.001185	19500	5.5	37.5	736	55.9	420
	0.019	0.076	0.001185	19500	5.5	37.5	736	55.9	190
	0.019	0.152	0.008854	19500	5.5	37.5	736	55.9	210
	0.019	0.076	0.008854	19500	5.5	37.5	736	55.9	230
	0.019	0.152	0.001185	19500	5.5	37.5	736	2710	3360
	0.019	0.076	0.001185	19500	5.5	37.5	736	1470	1840
	0.019	0.152	0.001185	19500	5.5	37.5	736	1470	1730
	0.019	0.076	0.001185	19500	5.5	37.5	736	2710	2920
	0.0368	0.2944	0.001185	17500	5.5	37.5	736	55.9	480
	0.0368	0.2944	0.001185	17500	5.5	37.5	736	55.9	440
	0.0368	0.1472	0.001185	17500	5.5	37.5	736	55.9	670
	0.0368	0.1472	0.001185	17500	5.5	37.5	736	55.9	670
	0.0368	0.2944	0.001185	17500	5.5	37.5	736	1470	2440
	0.0368	0.2944	0.001185	17500	5.5	37.5	736	1470	2600
	0.0368	0.1472	0.001185	17500	5.5	37.5	736	1470	2550
	0.0368	0.2944	0.001185	17500	5.5	37.5	736	2710	3520
	0.0368	0.2944	0.001185	17500	5.5	37.5	736	2710	4360
	0.0368	0.1472	0.001185	17500	5.5	37.5	736	2710	4400
Weiss et al. (1981)	0.2	0.6	0.004	83000	5.5	45	647	161.865	2000
	0.2	0.6	0.004	83000	5.5	45	647	161.865	3200
	0.2	0.6	0.004	83000	5.5	45	647	161.865	3500
	0.2	0.6	0.004	83000	5.5	45	647	800	7500
	0.2	0.6	0.004	83000	5.5	45	647	14000	10800
	0.2	0.6	0.004	83000	5.5	45	647	14300	16500
	0.2	0.6	0.004	83000	5.5	45	647	21400	10500
	0.2	0.6	0.004	83000	5.5	45	647	29200	28000
	0.2	0.6	0.004	83000	5.5	45	647	22500	28500
	0.2	0.6	0.025	83000	5.5	45	647	161.865	800
	0.2	0.6	0.025	83000	5.5	45	647	161.865	4700
	0.2	0.6	0.025	83000	5.5	45	647	10000	8000
	0.2	0.6	0.025	83000	5.5	45	647	10500	12000
	0.2	0.6	0.025	83000	5.5	45	647	14000	6800
	0.2	0.6	0.025	83000	5.5	45	647	17000	7800
	0.2	0.6	0.025	83000	5.5	45	647	17200	13600
	0.2	0.6	0.025	83000	5.5	45	647	20800	12700
	0.15	0.45	0.003	55000	5.5	31	812	203	1000
	0.15	0.45	0.003	55000	5.5	31	812	203	2500
	0.15	0.45	0.003	55000	5.5	31	812	203	4300
	0.15	0.45	0.003	55000	5.5	31	812	5900	7500
	0.15	0.45	0.003	55000	5.5	31	812	12700	3800
	0.15	0.45	0.003	55000	5.5	31	812	12400	5900
	0.15	0.45	0.003	55000	5.5	31	812	12300	9000
	0.15	0.45	0.003	55000	5.5	31	812	12500	11200
	0.15	0.45	0.003	55000	5.5	31	812	24900	11000
	0.15	0.45	0.003	55000	5.5	31	812	23600	15000
	0.15	0.45	0.003	55000	5.5	31	812	23700	16000
	0.15	0.45	0.003	55000	5.5	31	812	23600	17000
	0.15	0.45	0.024	55000	5.5	31	812	203	400
	0.15	0.45	0.024	55000	5.5	31	812	203	2000
	0.15	0.45	0.024	55000	5.5	31	812	10000	2700
	0.15	0.45	0.024	55000	5.5	31	812	9800	4700
	0.15	0.45	0.024	55000	5.5	31	812	10400	5300
	0.15	0.45	0.024	55000	5.5	31	812	12600	14300
	0.15	0.45	0.024	55000	5.5	31	812	19700	8000
	0.15	0.45	0.024	55000	5.5	31	812	21600	9500
	0.15	0.45	0.024	55000	5.5	31	812	19900	10800
	0.15	0.45	0.024	55000	5.5	31	812	24200	14400
	0.08	0.24	0.005	45000	5.5	27.5	853	213	2000
	0.08	0.24	0.005	45000	5.5	27.5	853	2000	2500

Table A.1 Ice rubble shear data from literature sources (continued).

Auth/Ref	Ice block **Min L** Li m	Median of **Max L** Lx m	Shear **Speed** V m/s	Ice block **Flex** σfl Pa	Pore fluid **Sal./Impur.** S % wt	**Bulk Porosity** e %	**Buoyant Weight** γ N/m^3	**Stress Normal** σn Pa	**Stress Shear** τ Pa
	0.08	0.24	0.005	45000	5.5	27.5	853	4000	2000
	0.08	0.24	0.005	45000	5.5	27.5	853	13800	5700
	0.08	0.24	0.005	45000	5.5	27.5	853	15200	7500
	0.08	0.24	0.005	45000	5.5	27.5	853	30800	7500
	0.08	0.24	0.025	45000	5.5	27.5	853	213	1500
	0.08	0.24	0.025	45000	5.5	27.5	853	213	2200
	0.08	0.24	0.025	45000	5.5	27.5	853	2200	2000
	0.08	0.24	0.025	45000	5.5	27.5	853	8000	2600
Hellmann (1984)	0.01	0.025	0.0109	1000000	0.001	35	542	190	800
	0.01	0.025	0.0109	1000000	0.001	35	542	540	1400
	0.01	0.025	0.0109	1000000	0.001	35	542	1350	2350
	0.01	0.025	0.0109	1000000	0.001	35	542	1450	2950
	0.01	0.025	0.0109	1000000	0.001	35	542	2090	2950
	0.01	0.025	0.0109	1000000	0.001	35	542	2200	3600
	0.01	0.025	0.0109	1000000	0.001	35	542	3200	5250
	0.01	0.025	0.0016	1000000	0.001	35	542	620	1450
	0.01	0.025	0.0016	1000000	0.001	35	542	1800	4600
	0.01	0.025	0.0016	1000000	0.001	35	542	2400	5950
	0.01	0.025	0.0016	1000000	0.001	35	542	3290	6920
	0.025	0.055	0.0107	1000000	0.001	35	542	400	560
	0.025	0.055	0.0107	1000000	0.001	35	542	460	1170
	0.025	0.055	0.0107	1000000	0.001	35	542	720	880
	0.025	0.055	0.0107	1000000	0.001	35	542	840	1280
	0.025	0.055	0.0107	1000000	0.001	35	542	1190	1300
	0.025	0.055	0.0107	1000000	0.001	35	542	1200	1650
	0.025	0.055	0.0107	1000000	0.001	35	542	2320	2380
	0.025	0.055	0.0107	1000000	0.001	35	542	3980	3910
	0.025	0.055	0.0107	1000000	0.001	35	542	4250	5230
	0.005	0.015	0.0107	50000	0.5	35	574	400	550
	0.005	0.015	0.0107	50000	0.5	35	574	390	1000
	0.005	0.015	0.0107	50000	0.5	35	574	1800	3350
	0.005	0.015	0.0107	50000	0.5	35	574	1630	3880
Fransson & Sandkvist (1985)	0.039	0.18	0.01	1000000	0.001	20	667	350	650
	0.039	0.18	0.01	1000000	0.001	20	667	575	1050
	0.039	0.18	0.01	1000000	0.001	20	667	625	800
	0.039	0.18	0.01	1000000	0.001	20	667	800	1270
	0.039	0.18	0.01	1000000	0.001	20	667	950	1060
	0.039	0.18	0.01	1000000	0.001	20	667	960	1570
	0.039	0.18	0.01	1000000	0.001	20	667	1560	1720
	0.039	0.18	0.01	1000000	0.001	20	667	1650	1480
	0.046	0.15	0.01	780000	0.001	20	667	450	640
	0.046	0.15	0.01	780000	0.001	20	667	650	660
	0.046	0.15	0.01	780000	0.001	20	667	1200	760
	0.046	0.15	0.01	780000	0.001	20	667	1250	660
	0.046	0.15	0.01	780000	0.001	20	667	1300	750
	0.046	0.15	0.01	780000	0.001	20	667	2320	1100
	0.046	0.15	0.01	780000	0.001	20	667	2990	1270
	0.008	0.07	0.01	37000	0.6	20	706	290	290
	0.008	0.07	0.01	37000	0.6	20	706	380	250
	0.008	0.07	0.01	37000	0.6	20	706	450	350
	0.008	0.07	0.01	37000	0.6	20	706	890	270
	0.008	0.07	0.01	37000	0.6	20	706	930	510
Urroz and Ettema (1987)	0.038	0.095	0.002	1000000	0.001	36	534	28	30
	0.038	0.095	0.002	1000000	0.001	36	534	65	38
	0.038	0.095	0.002	1000000	0.001	36	534	70	45
	0.038	0.095	0.002	1000000	0.001	36	534	64	50
	0.038	0.095	0.002	1000000	0.001	36	534	95	62
	0.038	0.095	0.002	1000000	0.001	36	534	80	80
	0.038	0.095	0.002	1000000	0.001	36	534	78	90
	0.038	0.095	0.002	1000000	0.001	36	534	125	80
	0.038	0.095	0.002	1000000	0.001	36	534	85	110
	0.038	0.095	0.002	1000000	0.001	36	534	90	150
	0.038	0.095	0.002	1000000	0.001	36	534	180	95
	0.038	0.095	0.002	1000000	0.001	36	534	170	160
	0.038	0.095	0.002	1000000	0.001	36	534	170	170
	0.038	0.095	0.002	1000000	0.001	36	534	150	160
	0.038	0.095	0.002	1000000	0.001	36	534	205	135
	0.038	0.095	0.002	1000000	0.001	36	534	250	180
	0.016	0.038	0.002	1000000	0.001	39	509	85	95

Table A.1 Ice rubble shear data from literature sources (continued).

Auth/Ref	Ice block Min L Li m	Median of Max L Lx m	Shear Speed V m/s	Ice block Flex σfl Pa	Pore fluid Sal./Impur. S % wt	Bulk Porosity e %	Buoyant Weight γ N/m^3	Stress Normal σn Pa	Stress Shear τ Pa
	0.016	0.038	0.002	1000000	0.001	39	509	85	120
	0.016	0.038	0.002	1000000	0.001	39	509	68	125
	0.016	0.038	0.002	1000000	0.001	39	509	90	135
	0.016	0.038	0.002	1000000	0.001	39	509	120	115
	0.016	0.038	0.002	1000000	0.001	39	509	130	170
	0.016	0.038	0.002	1000000	0.001	39	509	145	130
	0.016	0.038	0.002	1000000	0.001	39	509	145	150
	0.016	0.038	0.002	1000000	0.001	39	509	200	125
	0.016	0.038	0.002	1000000	0.001	39	509	180	215
	0.016	0.038	0.002	1000000	0.001	39	509	185	220
	0.016	0.038	0.002	1000000	0.001	39	509	225	285
	0.016	0.038	0.002	1000000	0.001	39	509	260	340
	0.016	0.038	0.002	1000000	0.001	39	509	320	320
	0.016	0.038	0.002	1000000	0.001	39	509	400	520
	0.016	0.038	0.002	1000000	0.001	39	509	475	560
	0.016	0.038	0.002	1000000	0.001	39	509	460	595
	0.018	0.018	0.002	1000000	0.001	23	642	45	75
	0.018	0.018	0.002	1000000	0.001	23	642	85	80
	0.018	0.018	0.002	1000000	0.001	23	642	95	90
	0.018	0.018	0.002	1000000	0.001	23	642	100	100
	0.018	0.018	0.002	1000000	0.001	23	642	130	100
	0.018	0.018	0.002	1000000	0.001	23	642	160	115
	0.018	0.018	0.002	1000000	0.001	23	642	180	130
	0.018	0.018	0.002	1000000	0.001	23	642	260	185
	0.018	0.018	0.002	1000000	0.001	23	642	255	195
	0.018	0.018	0.002	1000000	0.001	23	642	265	200
	0.018	0.018	0.002	1000000	0.001	23	642	350	260
	0.018	0.018	0.002	1000000	0.001	23	642	380	275
	0.038	0.095	0.002	1000000	0.001	41	492	15	30
	0.038	0.095	0.002	1000000	0.001	41	492	25	20
Case (1991)	0.038	0.095	0.002	1000000	0.001	41	492	25	35
	0.038	0.095	0.002	1000000	0.001	41	492	40	30
	0.038	0.095	0.002	1000000	0.001	41	492	45	30
	0.038	0.095	0.002	1000000	0.001	41	492	50	20
	0.038	0.095	0.002	1000000	0.001	41	492	50	15
	0.038	0.095	0.002	1000000	0.001	41	492	60	20
	0.038	0.095	0.002	1000000	0.001	41	492	60	30
	0.038	0.095	0.002	1000000	0.001	41	492	70	20
	0.038	0.095	0.002	1000000	0.001	41	492	95	45
	0.038	0.095	0.002	1000000	0.001	41	492	105	85
	0.038	0.095	0.002	1000000	0.001	41	492	110	50
	0.038	0.095	0.002	1000000	0.001	41	492	115	50
	0.038	0.095	0.002	1000000	0.001	41	492	160	75
	0.038	0.095	0.002	1000000	0.001	41	492	140	65
	0.038	0.038	0.002	1000000	0.001	40	500	40	80
	0.016	0.038	0.002	1000000	0.001	40	500	50	75
	0.016	0.038	0.002	1000000	0.001	40	500	65	75
	0.016	0.038	0.002	1000000	0.001	40	500	65	80
	0.016	0.038	0.002	1000000	0.001	40	500	90	100
	0.016	0.038	0.002	1000000	0.001	40	500	90	110
	0.016	0.038	0.002	1000000	0.001	40	500	100	120
	0.016	0.038	0.002	1000000	0.001	40	500	90	130
	0.016	0.038	0.002	1000000	0.001	40	500	80	130
	0.016	0.038	0.002	1000000	0.001	40	500	125	160
	0.016	0.038	0.002	1000000	0.001	40	500	130	200
	0.016	0.038	0.002	1000000	0.001	40	500	130	215
	0.016	0.038	0.002	1000000	0.001	40	500	180	230
	0.016	0.038	0.002	1000000	0.001	40	500	195	350
	0.016	0.038	0.002	1000000	0.001	40	500	210	330
	0.016	0.038	0.002	1000000	0.001	40	500	285	350
	0.018	0.018	0.002	1000000	0.001	31	575	90	60
	0.018	0.018	0.002	1000000	0.001	31	575	100	85
Bruneau (1994c)	0.018	0.018	0.002	1000000	0.001	31	575	100	50
	0.018	0.018	0.002	1000000	0.001	31	575	90	90
	0.018	0.018	0.002	1000000	0.001	31	575	125	75
	0.018	0.018	0.002	1000000	0.001	31	575	140	75
	0.018	0.018	0.002	1000000	0.001	31	575	165	100
	0.018	0.018	0.002	1000000	0.001	31	575	175	95
	0.018	0.018	0.002	1000000	0.001	31	575	200	120

Table A.1 Ice rubble shear data from literature sources (continued).

Auth/Ref	Ice block Min L Li m	Median of Max L Lx m	Shear Speed V m/s	Ice block Flex σfl Pa	Pore fluid Sal./Impur. S % wt	Bulk Porosity e %	Buoyant Weight γ N/m^3	Stress Normal σn Pa	Stress Shear τ Pa
	0.018	0.018	0.002	1000000	0.001	31	575	205	150
	0.018	0.018	0.002	1000000	0.001	31	575	275	175
	0.018	0.018	0.002	1000000	0.001	31	575	295	190
	0.018	0.018	0.002	1000000	0.001	31	575	370	220
	0.018	0.018	0.002	1000000	0.001	31	575	360	250
	0.018	0.018	0.002	1000000	0.001	31	575	410	260
	0.016	0.038	0.002	1000000	0.001	40	500	35	40
	0.016	0.038	0.002	1000000	0.001	40	500	65	40
	0.016	0.038	0.002	1000000	0.001	40	500	65	65
	0.016	0.038	0.002	1000000	0.001	40	500	65	75
	0.016	0.038	0.002	1000000	0.001	40	500	80	70
	0.016	0.038	0.002	1000000	0.001	40	500	85	50
	0.016	0.038	0.002	1000000	0.001	40	500	75	100
	0.016	0.038	0.002	1000000	0.001	40	500	75	105
	0.016	0.038	0.002	1000000	0.001	40	500	120	120
	0.016	0.038	0.002	1000000	0.001	40	500	180	220
	0.016	0.038	0.002	1000000	0.001	40	500	160	275
	0.016	0.038	0.002	1000000	0.001	40	500	290	300
	0.018	0.018	0.002	1000000	0.001	36	534	20	30
	0.018	0.018	0.002	1000000	0.001	36	534	35	50
	0.018	0.018	0.002	1000000	0.001	36	534	50	40
	0.018	0.018	0.002	1000000	0.001	36	534	55	50
	0.018	0.018	0.002	1000000	0.001	36	534	60	55
	0.018	0.018	0.002	1000000	0.001	36	534	60	45
	0.018	0.018	0.002	1000000	0.001	36	534	150	100
	0.018	0.018	0.002	1000000	0.001	36	534	140	125
	0.018	0.018	0.002	1000000	0.001	36	534	145	130
	0.018	0.018	0.002	1000000	0.001	36	534	200	215
	0.018	0.018	0.002	1000000	0.001	36	534	250	215
	0.018	0.018	0.002	1000000	0.001	36	534	310	200
Case (1991)	0.03	0.096	0.001	21840	0.5	30	446	1000	2100
	0.03	0.096	0.001	21840	0.5	30	446	1330	1860
	0.03	0.096	0.001	21840	0.5	30	446	420	1380
	0.03	0.096	0.001	25935	0.5	30	446	1360	2170
	0.03	0.096	0.001	25935	0.5	30	446	870	1210
	0.03	0.096	0.001	25935	0.5	30	446	1390	1930
	0.03	0.096	0.001	25935	0.5	30	446	1180	1400
	0.03	0.096	0.001	25935	0.5	30	446	560	870
	0.03	0.096	0.001	25935	0.5	30	446	540	1320
	0.03	0.096	0.001	25935	0.5	30	446	1380	2090
	0.03	0.096	0.001	25935	0.5	30	446	720	1630
	0.03	0.096	0.001	25935	0.5	30	446	960	1250
	0.03	0.096	0.001	25935	0.5	30	446	1240	1470
	0.03	0.096	0.001	25935	0.5	30	446	1140	1560
	0.03	0.096	0.001	25935	0.5	30	446	1510	1250
	0.03	0.096	0.001	24570	0.5	30	446	1750	2610
	0.03	0.096	0.001	24570	0.5	30	446	1650	1870
	0.03	0.096	0.001	24570	0.5	30	446	2410	2530
	0.03	0.096	0.001	24570	0.5	30	446	1460	2220
	0.03	0.096	0.001	24570	0.5	30	446	1020	1060
	0.03	0.096	0.001	21840	0.5	30	446	990	1220
	0.03	0.096	0.001	21840	0.5	30	446	980	970
	0.03	0.096	0.001	21840	0.5	30	446	820	930
	0.03	0.096	0.001	21840	0.5	30	446	1310	1390
	0.03	0.096	0.001	21840	0.5	30	446	670	1330
	0.03	0.096	0.001	21840	0.5	30	446	430	880
	0.03	0.096	0.001	23478	0.5	30	446	1800	2580
	0.03	0.096	0.001	23478	0.5	30	446	790	1440
	0.03	0.096	0.001	23478	0.5	30	446	1430	1700
	0.03	0.096	0.001	23478	0.5	30	446	1900	1690
	0.03	0.096	0.001	23478	0.5	30	446	930	1110
	0.03	0.096	0.001	23478	0.5	30	446	1490	1290
Bruneau (1994a)	0.018	0.035	0.001	2000000	0.001	35	542	115	2407
	0.018	0.035	0.001	2000000	0.001	35	542	115	3095
	0.018	0.035	0.001	2000000	0.001	35	542	638	2849
	0.018	0.035	0.001	2000000	0.001	35	542	640	3177
	0.018	0.035	0.001	2000000	0.001	35	542	1250	4452
	0.018	0.035	0.001	1500000	0.001	35	542	115	632
	0.018	0.035	0.001	1500000	0.001	35	542	640	1629

Table A.1 Ice rubble shear data from literature sources (continued).

Auth/Ref	Ice block Min L Li m	Median of Max L Lx m	Shear Speed V m/s	Ice block Flex σfl Pa	Pore fluid Sal./Impur. S % wt	Bulk Porosity e %	Buoyant Weight γ N/m^3	Stress Normal σn Pa	Stress Shear τ Pa
	0.018	0.035	0.001	1000000	0.001	35	542	115	1160
	0.018	0.035	0.001	1000000	0.001	35	542	640	2620
	0.018	0.035	0.001	1000000	0.001	35	542	1250	2604
	0.018	0.035	0.001	1000000	0.001	35	542	436	896
Bruneau et al. (1996)	0.03	0.0918	0.021	30000	0.5	30	687	662	1672
	0.03	0.0918	0.021	30000	0.5	30	687	392	1321
	0.03	0.0918	0.021	30000	0.5	30	687	354	1117
	0.03	0.0918	0.021	30000	0.5	30	687	1103	2168
	0.03	0.0918	0.021	30000	0.5	30	687	1746	2539
	0.03	0.0918	0.021	30000	0.5	30	687	343	1042
	0.03	0.0918	0.021	30000	0.5	30	687	1309	3018
	0.03	0.0918	0.021	30000	0.5	30	687	1924	3003
	0.03	0.0918	0.021	30000	0.5	30	687	784	1537
	0.03	0.0918	0.021	30000	0.5	30	687	2019	2222
	0.03	0.0918	0.021	30000	0.5	30	687	1175	1524
	0.05	0.153	0.021	30000	0.5	30	687	661	1461
	0.05	0.153	0.021	30000	0.5	30	687	964	1543
	0.05	0.153	0.021	30000	0.5	30	687	1655	2506
	0.05	0.153	0.021	30000	0.5	30	687	222	1012
	0.05	0.153	0.021	30000	0.5	30	687	1459	2200
	0.05	0.153	0.021	30000	0.5	30	687	757	1201
	0.05	0.153	0.021	30000	0.5	30	687	1201	1624
	0.05	0.153	0.021	30000	0.5	30	687	1862	2475
	0.05	0.153	0.021	30000	0.5	30	687	640	1559
	0.05	0.153	0.021	30000	0.5	30	687	1855	1875
	0.05	0.153	0.021	30000	0.5	30	687	1287	1444
McKenna et al. (1995b) PWC	0.0473	0.144738	0.069	18	0.5	32	547	150	175
	0.0473	0.144738	0.068	18	0.5	32	547	213	371
	0.0473	0.144738	0.073	18	0.5	32	547	139	281
	0.0473	0.144738	0.148	18	0.5	32	547	134	259
	0.0473	0.144738	0.13	18	0.5	32	547	191	383
	0.0473	0.144738	0.149	18	0.5	32	547	137	233
	0.0473	0.144738	0.068	18	0.5	32	547	115	675
	0.0473	0.144738	0.064	18	0.5	32	547	183	729
	0.0473	0.144738	0.07	18	0.5	32	547	96	529
	0.0473	0.144738	0.145	18	0.5	32	547	93	678
	0.0473	0.144738	0.145	18	0.5	32	547	115	653
	0.0473	0.144738	0.154	18	0.5	32	547	88	639
	0.0473	0.144738	0.074	18	0.5	32	547	134	194
	0.0473	0.144738	0.074	18	0.5	32	547	142	181
	0.0473	0.144738	0.074	18	0.5	32	547	57	200
	0.0471	0.144126	0.073	32	0.5	32	594	104	216
	0.0471	0.144126	0.07	32	0.5	32	594	217	274
	0.0471	0.144126	0.075	32	0.5	32	594	172	188
	0.0471	0.144126	0.072	32	0.5	32	594	140	703
	0.0471	0.144126	0.07	32	0.5	32	594	232	351
	0.0471	0.144126	0.075	32	0.5	32	594	104	309
	0.0471	0.144126	0.15	32	0.5	32	594	98	737
	0.0471	0.144126	0.139	32	0.5	32	594	187	552
	0.0471	0.144126	0.149	32	0.5	32	594	142	497
	0.0471	0.144126	0.07	32	0.5	32	594	154	388
	0.0471	0.144126	0.068	32	0.5	32	594	240	417
	0.0471	0.144126	0.076	32	0.5	32	594	107	378
	0.0471	0.144126	0.156	32	0.5	32	594	110	434
	0.0471	0.144126	0.135	32	0.5	32	594	217	593
	0.0471	0.144126	0.153	32	0.5	32	594	229	332
	0.051	0.15606	0.053	27.5	0.5	32	474	220	630
	0.051	0.15606	0.06	27.5	0.5	32	474	242	909
	0.051	0.15606	0.048	27.5	0.5	32	474	218	872
	0.051	0.15606	0.047	27.5	0.5	32	474	279	734
	0.051	0.15606	0.055	27.5	0.5	32	474	230	463
	0.0504	0.154224	0.059	34.5	0.5	40	406	276	258
	0.0504	0.154224	0.059	34.5	0.5	40	406	179	593
	0.0504	0.154224	0.066	34.5	0.5	40	406	177	394
	0.0504	0.154224	0.06	20.5	0.5	40	406	292	462
	0.0504	0.154224	0.057	20.5	0.5	40	406	177	1332
	0.0504	0.154224	0.059	20.5	0.5	40	406	231	472
	0.0495	0.15147	0.066	35.5	0.5	30	542	136	570
	0.0495	0.15147	0.058	35.5	0.5	30	542	282	619

Table A.1 Ice rubble shear data from literature sources (continued).

Auth/Ref	Ice block Min L Li m	Median of Max L Lx m	Shear Speed V m/s	Ice block Flex σfl Pa	Pore fluid Sal./Impur. S % wt	Bulk Porosity e %	Buoyant Weight γ N/m^3	Stress Normal σn Pa	Stress Shear τ Pa
	0.0495	0.15147	0.065	35.5	0.5	30	542	203	618
	0.0495	0.15147	0.063	25.5	0.5	30	542	179	710
	0.0495	0.15147	0.05	25.5	0.5	30	542	293	1167
	0.0495	0.15147	0.064	25.5	0.5	30	542	236	461
	0.0505	0.15453	0.065	37.5	0.5	27	544	166	548
	0.0505	0.15453	0.063	37.5	0.5	27	544	297	554
	0.0505	0.15453	0.074	37.5	0.5	27	544	109	485
	0.0505	0.15453	0.062	19.5	0.5	27	544	185	723
	0.0505	0.15453	0.055	19.5	0.5	27	544	223	1521
	0.0505	0.15453	0.068	19.5	0.5	27	544	161	493
	0.05	0.153	0.077	36.5	0.5	32	474	111	144
	0.05	0.153	0.072	36.5	0.5	32	474	230	188
	0.05	0.153	0.071	36.5	0.5	32	474	173	310
	0.05	0.153	0.076	36.5	0.5	32	474	206	72
	0.05	0.153	0.071	15.5	0.5	32	474	159	688
	0.05	0.153	0.073	15.5	0.5	32	474	128	461
	0.05	0.153	0.07	15.5	0.5	32	474	173	648
	0.0479	0.146574	0.067	73	0.5	35	446	158	488
	0.0479	0.146574	0.058	73	0.5	35	446	239	719
	0.0479	0.146574	0.063	73	0.5	35	446	152	681
	0.0479	0.146574	0.072	32	0.5	35	446	156	829
	0.0479	0.146574	0.061	32	0.5	35	446	216	1285
	0.0479	0.146574	0.065	32	0.5	35	446	163	646
McKenna (1996) JIP	0.0497	0.152082	0.056	55.5	0.5	20.7	786	491	733
	0.0497	0.152082	0.049	55.5	0.5	20.7	786	437	1052
	0.0497	0.152082	0.064	55.5	0.5	20.7	786	301	541
	0.0497	0.152082	0.049	37.5	0.5	20.7	786	363	1235
	0.0497	0.152082	0.051	37.5	0.5	20.7	786	354	1275
	0.0497	0.152082	0.055	37.5	0.5	20.7	786	367	640
	0.0497	0.152082	0.055	37.5	0.5	20.7	786	363	1231
	0.0497	0.152082	0.065	37.5	0.5	20.7	786	221	903
	0.0497	0.152082	0.066	37.5	0.5	20.7	786	147	964
	0.0497	0.152082	0.053	37.5	0.5	20.7	786	344	1127
	0.0497	0.152082	0.055	37.5	0.5	20.7	786	290	1303
	0.047	0.14382	0.061	117	0.5	26.5	714	266	415
	0.047	0.14382	0.066	117	0.5	26.5	714	357	531
	0.047	0.14382	0.075	117	0.5	26.5	714	143	412
	0.047	0.14382	0.074	117	0.5	26.5	714	152	445
	0.047	0.14382	0.054	117	0.5	26.5	714	362	805
	0.047	0.14382	0.066	117	0.5	26.5	714	276	748
	0.047	0.14382	0.053	81.5	0.5	26.5	714	393	994
	0.047	0.14382	0.069	81.5	0.5	26.5	714	332	650
	0.047	0.14382	0.067	81.5	0.5	26.5	714	161	549
	0.047	0.14382	0.055	81.5	0.5	26.5	714	411	575
	0.047	0.14382	0.061	81.5	0.5	26.5	714	308	769
	0.047	0.14382	0.051	81.5	0.5	26.5	714	317	1635
	0.047	0.14382	0.05	81.5	0.5	26.5	714	410	901
	0.047	0.14382	0.072	81.5	0.5	26.5	714	156	545
	0.047	0.14382	0.07	81.5	0.5	26.5	714	125	709
	0.047	0.14382	0.053	81.5	0.5	26.5	714	406	1334
	0.047	0.14382	0.066	81.5	0.5	26.5	714	308	1067
	0.051	0.15606	0.064	59.5	0.5	15	892	301	489
	0.051	0.15606	0.069	59.5	0.5	15	892	301	396
	0.051	0.15606	0.059	59.5	0.5	15	892	452	486
	0.051	0.15606	0.066	59.5	0.5	15	892	458	280
	0.051	0.15606	0.053	59.5	0.5	15	892	519	599
	0.051	0.15606	0.057	59.5	0.5	15	892	513	835
	0.051	0.15606	0.065	44	0.5	15	892	323	514
	0.051	0.15606	0.065	44	0.5	15	892	329	333
	0.051	0.15606	0.055	44	0.5	15	892	508	927
	0.051	0.15606	0.063	44	0.5	15	892	519	324
	0.051	0.15606	0.05	44	0.5	15	892	575	924
	0.051	0.15606	0.055	44	0.5	15	892	603	667
	0.052	0.15912	0.075	61.5	0.5	22.5	813	193	493
	0.052	0.15912	0.077	61.5	0.5	22.5	813	224	353
	0.052	0.15912	0.068	61.5	0.5	22.5	813	336	400
	0.052	0.15912	0.071	61.5	0.5	22.5	813	336	404
	0.052	0.15912	0.069	61.5	0.5	22.5	813	310	477
	0.052	0.15912	0.072	61.5	0.5	22.5	813	290	409

Table A.1 Ice rubble shear data from literature sources (continued).

Auth/Ref	Ice block Min L Li m	Median of Max L Lx m	Shear Speed V m/s	Ice block Flex σfl Pa	Pore fluid Sal./Impur. S % wt	Bulk Porosity e %	Buoyant Weight γ N/m^3	Stress Normal σn Pa	Stress Shear τ Pa
	0.05	0.153	0.064	24.5	0.5	22.5	730	370	593
	0.05	0.153	0.066	24.5	0.5	22.5	730	356	308
	0.05	0.153	0.067	24.5	0.5	22.5	730	294	683
	0.05	0.153	0.071	24.5	0.5	22.5	730	303	337
	0.05	0.153	0.071	24.5	0.5	22.5	730	165	579
	0.05	0.153	0.076	24.5	0.5	22.5	730	173	406
	0.047	0.14382	0.069	21.5	0.5	12.25	766	112	1258
	0.047	0.14382	0.074	21.5	0.5	12.25	766	225	263
	0.047	0.14382	0.065	21.5	0.5	12.25	766	236	605
	0.047	0.14382	0.072	21.5	0.5	12.25	766	340	241
	0.047	0.14382	0.074	21.5	0.5	12.25	766	153	449
	0.047	0.14382	0.074	21.5	0.5	12.25	766	149	322
	0.05	0.153	0.064	29.5	0.5	18	869	358	477
	0.05	0.153	0.075	29.5	0.5	18	869	342	182
	0.05	0.153	0.053	29.5	0.5	18	869	516	1109
	0.05	0.153	0.06	29.5	0.5	18	869	516	643
	0.05	0.153	0.063	29.5	0.5	18	869	500	433
	0.05	0.153	0.057	29.5	0.5	18	869	471	628
	0.05	0.153	0.064	29.5	0.5	18	869	434	382
	0.05	0.153	0.066	29.5	0.5	18	869	326	303
	0.05	0.153	0.071	29.5	0.5	18	869	304	255
Lehmus and Karna (1995)	0.047	0.188	0.01	1000000	0.001	33	559	168	8200
	0.047	0.188	0.01	1000000	0.001	31	575	173	3870
	0.037	0.1295	0.01	1000000	0.001	32	567	170	6260
	0.037	0.1295	0.01	1000000	0.001	42	484	1585	12820
	0.037	0.1295	0.01	1000000	0.001	30	584	175	25190
	0.045	0.2025	0.01	1000000	0.001	28	600	180	9400
	0.045	0.2025	0.01	1000000	0.001	37	525	1598	6300
	0.045	0.2025	0.01	1000000	0.001	32	567	1610	8080
	0.045	0.2025	0.01	1000000	0.001	37	525	158	8480
	0.045	0.2025	0.01	1000000	0.001	39	509	1593	12520
	0.048	0.192	0.01	1000000	0.001	29	592	178	9380
	0.048	0.192	0.01	1000000	0.001	37	525	1598	8980
	0.04	0.18	0.01	1000000	0.001	30	584	175	1420
	0.041	0.1845	0.01	1000000	0.001	40	500	150	3050
	0.041	0.1845	0.01	1000000	0.001	37	525	158	2350
	0.041	0.1845	0.01	1000000	0.001	32	567	170	1400
	0.042	0.189	0.01	1000000	0.001	32	567	170	4150
	0.042	0.189	0.01	1000000	0.001	31	575	1613	6610
	0.042	0.189	0.01	1000000	0.001	36	534	1600	15160
	0.042	0.189	0.01	1000000	0.001	34	550	1605	10490
	0.042	0.189	0.01	1000000	0.001	35	542	1603	8300
Cheng and Tatinclaux (1977)	0.008	0.038	0.00025	1000000	0.001	35	542	25	2532
	0.008	0.038	0.0005	1000000	0.001	35	542	25	960
	0.008	0.038	0.001	1000000	0.001	35	542	25	400
	0.008	0.038	0.001993	1000000	0.001	35	542	25	200
	0.008	0.038	0.002999	1000000	0.001	35	542	25	200
	0.008	0.038	0.003999	1000000	0.001	35	542	25	120
	0.008	0.038	0.004996	1000000	0.001	35	542	25	101
	0.008	0.038	0.005995	1000000	0.001	35	542	25	101
	0.008	0.038	0.00025	1000000	0.001	35	542	41	2841
	0.008	0.038	0.0005	1000000	0.001	35	542	41	2395
	0.008	0.038	0.001	1000000	0.001	35	542	41	720
	0.008	0.038	0.001993	1000000	0.001	35	542	41	175
	0.008	0.038	0.002999	1000000	0.001	35	542	41	151
	0.008	0.038	0.003999	1000000	0.001	35	542	41	144
	0.008	0.038	0.004996	1000000	0.001	35	542	41	161
	0.008	0.038	0.005995	1000000	0.001	35	542	41	175
	0.008	0.038	0.00025	1000000	0.001	35	542	58	3067
	0.008	0.038	0.0005	1000000	0.001	35	542	58	1656
	0.008	0.038	0.001	1000000	0.001	35	542	58	605
	0.008	0.038	0.001993	1000000	0.001	35	542	58	398
	0.008	0.038	0.002999	1000000	0.001	35	542	58	394
	0.008	0.038	0.003999	1000000	0.001	35	542	58	228
	0.008	0.038	0.004996	1000000	0.001	35	542	58	221
	0.008	0.038	0.005995	1000000	0.001	35	542	58	221
	0.008	0.038	0.0005	1000000	0.001	35	542	74	2438
	0.008	0.038	0.001	1000000	0.001	35	542	74	2385
	0.008	0.038	0.001993	1000000	0.001	35	542	74	562

Table A.1 Ice rubble shear data from literature sources (continued).

Auth/Ref	Ice block **Min L** Li m	Median of **Max L** Lx m	Shear **Speed** V m/s	Ice block **Flex** σfl Pa	Pore fluid **Sal./Impur.** S % wt	Bulk **Porosity** e %	Buoyant **Weight** γ N/m^3	Stress **Normal** σn Pa	Stress **Shear** τ Pa
	0.008	0.038	0.002999	1000000	0.001	35	542	74	322
	0.008	0.038	0.003999	1000000	0.001	35	542	74	240
	0.008	0.038	0.004996	1000000	0.001	35	542	74	202
	0.008	0.038	0.005995	1000000	0.001	35	542	74	168
	0.008	0.038	0.00025	1000000	0.001	35	542	25	1666
	0.008	0.038	0.0005	1000000	0.001	35	542	25	780
	0.008	0.038	0.001	1000000	0.001	35	542	25	720
	0.008	0.038	0.001999	1000000	0.001	35	542	25	433
	0.008	0.038	0.002999	1000000	0.001	35	542	25	331
	0.008	0.038	0.003999	1000000	0.001	35	542	25	227
	0.008	0.038	0.004996	1000000	0.001	35	542	25	221
	0.008	0.038	0.005995	1000000	0.001	35	542	25	221
	0.008	0.038	0.00025	1000000	0.001	35	542	41	3000
	0.008	0.038	0.0005	1000000	0.001	35	542	41	1502
	0.008	0.038	0.001	1000000	0.001	35	542	41	696
	0.008	0.038	0.001999	1000000	0.001	35	542	41	446
	0.008	0.038	0.002999	1000000	0.001	35	542	41	331
	0.008	0.038	0.003999	1000000	0.001	35	542	41	302
	0.008	0.038	0.004996	1000000	0.001	35	542	41	259
	0.008	0.038	0.005995	1000000	0.001	35	542	41	259
	0.008	0.038	0.00025	1000000	0.001	35	542	58	4517
	0.008	0.038	0.0005	1000000	0.001	35	542	58	2371
	0.008	0.038	0.001	1000000	0.001	35	542	58	1022
	0.008	0.038	0.001999	1000000	0.001	35	542	58	379
	0.008	0.038	0.002999	1000000	0.001	35	542	58	451
	0.008	0.038	0.003999	1000000	0.001	35	542	58	288
	0.008	0.038	0.004996	1000000	0.001	35	542	58	259
	0.008	0.038	0.005995	1000000	0.001	35	542	58	235
	0.008	0.038	0.001	1000000	0.001	35	542	74	2688
	0.008	0.038	0.001999	1000000	0.001	35	542	74	778
	0.008	0.038	0.002999	1000000	0.001	35	542	74	595
	0.008	0.038	0.003999	1000000	0.001	35	542	74	446
	0.008	0.038	0.004996	1000000	0.001	35	542	74	446
	0.008	0.038	0.005995	1000000	0.001	35	542	74	446
	0.008	0.038	0.00025	1000000	0.001	35	542	25	4569
	0.008	0.038	0.0005	1000000	0.001	35	542	25	2481
	0.008	0.038	0.001	1000000	0.001	35	542	25	902
	0.008	0.038	0.001999	1000000	0.001	35	542	25	398
	0.008	0.038	0.002999	1000000	0.001	35	542	25	322
	0.008	0.038	0.003999	1000000	0.001	35	542	25	230
	0.008	0.038	0.004996	1000000	0.001	35	542	25	230
	0.008	0.038	0.005995	1000000	0.001	35	542	25	110
	0.008	0.038	0.00025	1000000	0.001	35	542	41	4377
	0.008	0.038	0.0005	1000000	0.001	35	542	41	2803
	0.008	0.038	0.001	1000000	0.001	35	542	41	1397
	0.008	0.038	0.001999	1000000	0.001	35	542	41	600
	0.008	0.038	0.002999	1000000	0.001	35	542	41	499
	0.008	0.038	0.003999	1000000	0.001	35	542	41	403
	0.008	0.038	0.004996	1000000	0.001	35	542	41	300
	0.008	0.038	0.005995	1000000	0.001	35	542	41	252
	0.008	0.038	0.00025	1000000	0.001	35	542	58	4973
	0.008	0.038	0.0005	1000000	0.001	35	542	58	3144
	0.008	0.038	0.001	1000000	0.001	35	542	58	1286
	0.008	0.038	0.001999	1000000	0.001	35	542	58	643
	0.008	0.038	0.002999	1000000	0.001	35	542	58	427
	0.008	0.038	0.003999	1000000	0.001	35	542	58	427
	0.008	0.038	0.004996	1000000	0.001	35	542	58	322
	0.008	0.038	0.005995	1000000	0.001	35	542	58	322
	0.008	0.038	0.00025	1000000	0.001	35	542	74	5400
	0.008	0.038	0.0005	1000000	0.001	35	542	74	3000
	0.008	0.038	0.001	1000000	0.001	35	542	74	1608
	0.008	0.038	0.001999	1000000	0.001	35	542	74	888
	0.008	0.038	0.002999	1000000	0.001	35	542	74	667
	0.008	0.038	0.003999	1000000	0.001	35	542	74	557
	0.008	0.038	0.004996	1000000	0.001	35	542	74	557
	0.008	0.038	0.005995	1000000	0.001	35	542	74	557
	0.004	0.025	0.000198	1000000	0.001	35	542	21	3651
	0.004	0.025	0.000378	1000000	0.001	35	542	21	2466
	0.004	0.025	0.000808	1000000	0.001	35	542	21	1018

Table A.1 Ice rubble shear data from literature sources (continued).

Auth/Ref	**Ice block Min L** Li m	**Median of Max L** Lx m	**Shear Speed** V m/s	**Ice block Flex** σfl Pa	**Pore fluid Sal./Impur.** S % wt	**Bulk Porosity** e %	**Buoyant Weight** γ N/m^3	**Stress Normal** σn Pa	**Stress Shear** τ Pa
	0.004	0.025	0.001183	1000000	0.001	35	542	21	546
	0.004	0.025	0.001667	1000000	0.001	35	542	21	341
	0.004	0.025	0.000378	1000000	0.001	35	542	41	6207
	0.004	0.025	0.000808	1000000	0.001	35	542	41	2698
	0.004	0.025	0.001183	1000000	0.001	35	542	41	1732
	0.004	0.025	0.001667	1000000	0.001	35	542	41	1313
	0.004	0.025	0.000808	1000000	0.001	35	542	62	6616
	0.004	0.025	0.001183	1000000	0.001	35	542	62	4481
	0.004	0.025	0.001667	1000000	0.001	35	542	62	3384
	0.004	0.025	0.000198	1000000	0.001	35	542	21	1946
	0.004	0.025	0.000378	1000000	0.001	35	542	21	833
	0.004	0.025	0.000808	1000000	0.001	35	542	21	495
	0.004	0.025	0.001183	1000000	0.001	35	542	21	252
	0.004	0.025	0.001667	1000000	0.001	35	542	21	160
	0.004	0.025	0.000198	1000000	0.001	35	542	41	5798
	0.004	0.025	0.000378	1000000	0.001	35	542	41	2103
	0.004	0.025	0.000808	1000000	0.001	35	542	41	1125
	0.004	0.025	0.001183	1000000	0.001	35	542	41	568
	0.004	0.025	0.001667	1000000	0.001	35	542	41	399
	0.004	0.025	0.000198	1000000	0.001	35	542	62	9958
	0.004	0.025	0.000378	1000000	0.001	35	542	62	4842
	0.004	0.025	0.000808	1000000	0.001	35	542	62	2040
	0.004	0.025	0.001183	1000000	0.001	35	542	62	1288
	0.004	0.025	0.001667	1000000	0.001	35	542	62	1088
	0.004	0.025	0.000198	1000000	0.001	35	542	21	2926
	0.004	0.025	0.000396	1000000	0.001	35	542	21	1805
	0.004	0.025	0.000805	1000000	0.001	35	542	21	955
	0.004	0.025	0.001201	1000000	0.001	35	542	21	587
	0.004	0.025	0.001634	1000000	0.001	35	542	21	235
	0.004	0.025	0.000198	1000000	0.001	35	542	41	5182
	0.004	0.025	0.000396	1000000	0.001	35	542	41	3141
	0.004	0.025	0.000805	1000000	0.001	35	542	41	1278
	0.004	0.025	0.001201	1000000	0.001	35	542	41	901
	0.004	0.025	0.001634	1000000	0.001	35	542	41	503
	0.004	0.025	0.000195	1000000	0.001	35	542	62	9847
	0.004	0.025	0.000396	1000000	0.001	35	542	62	5333
	0.004	0.025	0.000805	1000000	0.001	35	542	62	1877
	0.004	0.025	0.001201	1000000	0.001	35	542	62	1162
	0.004	0.025	0.001634	1000000	0.001	35	542	62	543
	0.004	0.025	0.000195	1000000	0.001	35	542	21	2034
	0.004	0.025	0.000396	1000000	0.001	35	542	21	1180
	0.004	0.025	0.000805	1000000	0.001	35	542	21	737
	0.004	0.025	0.001201	1000000	0.001	35	542	21	539
	0.004	0.025	0.001634	1000000	0.001	35	542	21	277
	0.004	0.025	0.000195	1000000	0.001	35	542	41	5937
	0.004	0.025	0.000396	1000000	0.001	35	542	41	3610
	0.004	0.025	0.000805	1000000	0.001	35	542	41	1452
	0.004	0.025	0.001201	1000000	0.001	35	542	41	698
	0.004	0.025	0.001634	1000000	0.001	35	542	41	535
	0.004	0.025	0.000198	1000000	0.001	35	542	62	8221
	0.004	0.025	0.000396	1000000	0.001	35	542	62	4489
	0.004	0.025	0.000805	1000000	0.001	35	542	62	1711
	0.004	0.025	0.001201	1000000	0.001	35	542	62	1142
	0.004	0.025	0.001634	1000000	0.001	35	542	62	772

APPENDIX B

Table B.1 lists laboratory ice rubble/structure interaction data from literature sources referred to in Subsection 4.3.3 - ridge/structure interaction regression analysis.

Table B.1 Ice rubble/structure interaction data.

Reference	Dummy variables	Boundary conditions: Rubble extent* contin. = 1 disc. = 2	Boundary conditions: Structure: 2-d or 3-d 2-d = 1 3-d = 2	Boundary conditions: Waterline confine. N = 1 Y = 2	Structural diameter m	Keel width m	Keel depth m	Keel area m^2	Speed m/s	Peak load N	Friction angle deg	Cohesion c Pa	Buoyant weight N/m^3
Cheng and Tatinclaux (1977)	1	1	1	1	0.9144		0.0762		0.000155	386.4	46	1	542
	1	1	1	1	0.9144		0.0762		0.000283	76.1	46	1	542
	1	1	1	1	0.9144		0.0762		0.000347	90.7	46	1	542
	1	1	1	1	0.9144		0.0762		0.000366	54.3	46	1	542
	1	1	1	1	0.9144		0.0762		0.000655	46.5	46	1	542
	1	1	1	1	0.9144		0.0762		0.000978	25.5	46	1	542
	1	1	1	1	0.9144		0.0762		0.001323	18.7	46	1	542
	1	1	1	1	0.9144		0.1524		0.000652	146.5	46	1	542
	1	1	1	1	0.9144		0.1524		0.001042	95.0	46	1	542
	1	1	1	1	0.9144		0.1524		0.001445	78.9	46	1	542
	1	1	1	1	0.9144		0.1524		0.002326	47.3	46	1	542
	1	1	1	1	0.9144		0.2286		0.00086	371.9	46	1	542
	1	1	1	1	0.9144		0.2286		0.001286	291.9	46	1	542
	1	1	1	1	0.9144		0.2286		0.001829	183.0	46	1	542
	1	1	1	1	0.9144		0.2286		0.002807	156.5	46	1	542
Kein. and Ny. (1978)	1	1	1	1	0.3		0.174		0.025	24.0	47	11	669
Prodanovic (1979)	1	1	2	1	0.152		0.075		0.008854	11.4	47	260	736
	1	1	2	1	0.152		0.145		0.008854	24.3	47	260	736
	1	1	2	1	0.152		0.145		0.008854	30.4	47	260	736
	1	1	2	1	0.152		0.075		0.008854	31.9	53	580	736
	1	1	2	1	0.152		0.075		0.008854	36.5	53	580	736
	1	1	2	1	0.152		0.09		0.008854	73.0	53	580	736
	1	1	2	1	0.152		0.145		0.008854	87.4	53	580	736
	1	1	2	1	0.152		0.145		0.008854	97.3	53	580	736
	1	1	2	1	0.152		0.28		0.008854	127.7	53	580	736
	1	1	2	1	0.152		0.04		0.001185	7.6	47	260	736
	1	1	2	1	0.152		0.075		0.001185	50.2	53	580	736
	1	1	2	1	0.152		0.09		0.001185	63.8	53	580	736
	1	1	2	1	0.152		0.145		0.001185	54.7	53	580	736
	1	1	2	1	0.152		0.145		0.001185	65.4	53	580	736
	1	1	2	1	0.152		0.28		0.001185	120.1	53	580	736
	1	1	2	1	0.304		0.04		0.001185	9.1	47	260	736
	1	1	2	1	0.304		0.075		0.001185	53.2	53	580	736
	1	1	2	1	0.304		0.09		0.001185	106.4	53	580	736
	1	1	2	1	0.304		0.145		0.001185	97.3	53	580	736
	1	1	2	1	0.304		0.145		0.001185	118.6	53	580	736
	1	1	2	1	0.304		0.28		0.001185	264.5	53	580	736
	1	1	2	1	0.304		0.28		0.001185	282.7	53	580	736
	1	1	2	1	0.304		0.04		0.001185	18.2	47	260	736
	1	1	2	1	0.304		0.075		0.001185	24.3	47	260	736
	1	1	2	1	0.304		0.075		0.001185	27.4	47	260	736

Table B.1 Ice rubble/structure interaction data (continued).

Reference	Dummy variables	Boundary conditions			Structural diameter m	Keel width m	Keel depth m	Keel area m^2	Speed m/s	Peak load N	Friction angle deg	Cohesion c Pa	Buoyant weight N/m^3
		Rubble extent* contin. = 1 disc. = 2	Structure: 2-d or 3-d 2-d = 1 3-d = 2	Waterline confine. N = 1 Y = 2									
	1	1	2	1	0.304		0.145		0.001185	57.8	47	260	736
	1	1	2	1	0.304		0.145		0.001185	60.8	47	260	736
	1	1	2	1	0.304		0.075		0.001185	60.8	53	580	736
	1	1	2	1	0.304		0.09		0.001185	109.4	53	580	736
	1	1	2	1	0.304		0.145		0.001185	94.2	53	580	736
	1	1	2	1	0.304		0.145		0.001185	191.5	53	580	736
	1	1	2	1	0.304		0.28		0.001185	252.3	53	580	736
	1	1	2	1	0.304		0.28		0.001185	285.8	53	580	736
Hellmann (1984)	1	1	2	1	0.1		0.2		0.0105	30.0	54	580	542
	1	1	2	1	0.1		0.4		0.0105	352.0	54	580	542
	1	1	2	1	0.1		0.5		0.0105	345.0	54	580	542
	1	1	2	1	0.1		0.6		0.0105	470.0	54	580	542
	1	1	2	1	0.1		0.8		0.0105	800.0	54	580	542
	1	1	2	1	0.1		0.4		0.0005	630.0	61	420	542
	1	1	2	1	0.1		0.4		0.0012	625.0	61	420	542
	1	1	2	1	0.1		0.4		0.0022	525.0	61	420	542
	1	1	2	1	0.1		0.4		0.0045	290.0	61	420	542
	1	1	2	1	0.1		0.4		0.0102	565.0	54	580	542
	1	1	2	1	0.1		0.4		0.0102	355.0	54	580	542
	1	1	2	1	0.1		0.4		0.02	195.0	54	580	542
	1	1	2	1	0.1		0.4		0.023	85.0	54	580	542
	1	1	2	1	0.1		0.4		0.08	85.0	54	580	542
	1	1	2	1	0.1		0.4		0.25	60.0	54	580	542
Bruneau (1994a) *Submerged rubble*	1	2	2	1	0.114	0.45	0.2	0.09	0.006	40.0	55	2400	588
	1	2	2	1	0.114	0.45	0.2	0.09	0.006	23.5	55	2400	588
	1	2	2	1	0.114	0.45	0.1	0.045	0.006	8.0	55	2400	588
	1	2	2	1	0.114	0.3	0.2	0.06	0.006	7.5	55	2400	588
	1	2	2	1	0.114	0.45	0.2	0.09	0.006	19.0	55	900	588
	1	1	2	1	0.114		0.2		0.006	50.0	55	900	588
	1	2	2	1	0.114	0.45	0.25	0.1125	0.006	41.0	55	900	588
	1	1	2	1	0.114		0.25		0.006	24.0	55	900	588
	1	1	2	1	0.114		0.25		0.006	37.0	55	900	588
Dry rubble	1	2	2	2	0.114	0.45	0.2	0.09	0.006	180.0			5297
	1	2	2	2	0.114	0.45	0.2	0.09	0.006	120.0			5297
	1	2	2	2	0.114	0.45	0.2	0.09	0.006	52.0			5297
	1	2	2	2	0.114	0.45	0.2	0.09	0.006	57.0			5297
	1	2	2	2	0.114	0.45	0.2	0.09	0.006	250.0			5297
	1	1	2	2	0.114		0.2		0.006	250.0			5297
	1	2	2	2	0.114	0.45	0.1	0.045	0.006	72.0			5297
	1	2	2	2	0.114	0.45	0.1	0.0225	0.006	52.0			5297

Table B.1 Ice rubble/structure interaction data (continued).

Reference	Dummy variables	Boundary conditions			Structural diameter m	Keel width m	Keel depth m	Keel area m^2	Speed m/s	Peak load N	Friction angle deg	Cohesion c Pa	Buoyant weight N/m^3
		Rubble extent* contin. = 1 disc. = 2	Structure: 2-d or 3-d 2-d = 1 3-d = 2	Waterline confine. N = 1 Y = 2									
Timco and Cornett (1995)	1	2	2	2	0.333	2	0.318	0.636	0.09	1350.0			536
	1	2	2	2	0.333	1	0.318	0.318	0.09	410.0			536
	1	2	2	2	0.333	1	0.363	0.363	0.09	470.0			536
	1	2	2	2	0.333	1	0.003	0.003	0.09	70.0			536
	1	2	2	2	0.333	1	0.003	0.003	0.09	180.0			536
	1	2	2	2	0.333	1	0.273	0.273	0.09	170.0			536
	1	2	2	2	0.333	1	0.408	0.408	0.09	900.0			536
	1	2	2	2	0.333	0.8	0.003	0.0024	0.09	270.0			536
	1	2	2	2	0.333	1	0.363	0.363	0.09	600.0			536
	1	2	2	2	0.333	1	0.453	0.453	0.27	1400.0			536
	1	2	2	2	0.333	1	0.318	0.318	0.27	1900.0			536
McKenna et al. (1995a)	1	2	2	1	0.32	2	0.58	0.59	0.019	332.0	36	438	725
	1	2	2	1	0.32	2	0.58	0.59	0.187	331.0	36	438	725
	1	2	2	1	0.32	3	0.67	1	0.187	852.0	36	438	725
	1	2	2	1	0.32	3	0.67	1	0.131	592.0	36	438	725
	1	2	2	1	0.32	3	0.67	1	0.075	692.0	36	438	725
	1	2	2	1	0.32	3	0.67	1	0.019	541.0	36	438	725
McKenna et al. (1995b)	1	2	2	2	0.8	4.5	1.02	3.8	0.424	3110.0	36	438	487
	1	2	2	2	0.8	4.5	1.02	3.8	0.141	2650.0	36	438	487
	1	2	2	2	0.8	4.9	1.02	4.24	0.141	2170.0	36	438	500
	1	2	2	2	0.8	4.9	0.78	4.24	0.141	1080.0	36	438	500
	1	2	2	2	0.8	6	1.02	3.52	0.141	2760.0	36	438	549
	1	2	2	2	0.8	6	1.02	3.52	0.0283	3110.0	36	438	549
	1	2	2	2	0.8	6	0.82	3.36	0.141	2440.0	36	438	738
	1	2	2	2	0.8	6	0.58	3.36	0.141	870.0	36	438	738
	1	2	2	2	0.8	4.6	0.97	3.41	0.141	2810.0	36	438	487
	1	2	2	2	0.8	4.5	1.02	3.77	0.141	3950.0	36	438	599
	1	2	2	2	0.8	4.5	0.78	3.77	0.141	1560.0	36	438	599
McKenna (1996)	1	2	2	2	0.8	3.5	0.55	1.218	0.07	790.0	36	438	716
	1	2	2	2	0.8	3.5	0.79	2.154	0.07	2610.0	36	438	716
	1	2	2	2	0.8	4	1	2	0.07	4530.0	36	438	890
	1	2	2	2	0.8	4	1	2.491	0.07	3770.0	36	438	890
	1	2	2	2	0.8	6	0.52	3.101	0.07	1540.0	36	438	816
	1	2	2	2	0.8	3.5	0.89	1.938	0.07	2540.0	36	438	780
	1	2	2	2	0.8	3.5	0.89	1.938	0.07	3120.0	36	438	780
	1	2	2	2	0.8	1.75	0.48	0.553	0.07	860.0	36	438	685
	1	2	2	2	0.8	1.75	0.48	0.553	0.07	610.0	36	438	685
	1	2	2	2	1.8	3.5	0.68	1.418	0.07	3520.0	36	438	839
	1	2	2	2	1.8	4	0.68	1.831	0.07	3690.0	36	438	753
	1	2	2	2	1.8	4	0.99	2.848	0.07	6580.0	36	438	753

APPENDIX C

The tables listed in this appendix are referred to in Sections 5.2 and 5.3 - Sand tests. Table C.1 lists the test conditions and results for the sand test experiments with vertical structures and C.2 lists those for conical structures.

Table C.1 Sand test conditions for vertical structures.

Element	Parameter	Test	Keel Shape & size mm	Pier Shape & size mm	Pier diameter mm	Keel width mm	Keel depth mm	Depth/diam	Wid/diam	Maximum force N	Dist. to max. F m
KEEL	Shape	NS01	Trap 320	Cyl 114	114	320	76	0.67	2.81	35.4	0.118
		NS02	Tria 320	Cyl 114	114	320	94	0.82	2.81	33.23	0.093
		NS03	Sin 320	Cyl 114	114	320	74	0.65	2.81	32.62	0.091
		NS04	Trap 450	Cyl 114	114	450	58	0.51	3.95	29.84	0.168
		NS05	Tria 450	Cyl 114	114	450	65	0.57	3.95	31.11	0.180
KEEL	Wid/Dia	'01,20,f21,3	Trap 320	Cyl 114	114	320	76	0.67	2.81	35.3	0.094
		NS06	Trap320+50	Cyl 114	114	370	76	0.67	3.25	45.92	0.106
		NS07	Trap 320+100	Cyl 114	114	420	76	0.67	3.68	57.34	0.118
		NS08	Trap 320+150	Cyl 114	114	470	76	0.67	4.12	58.33	0.174
		NS09	Trap 320+200	Cyl 114	114	520	76	0.67	4.56	69.77	0.190
		NS10	Trap 320+250	Cyl 114	114	570	76	0.67	5.00	71.68	0.221
		NS12	Trap 160	Cyl 60	60	160	38	0.63	2.67	5.2	0.043
		NS13	Trap 160+50	Cyl 60	60	210	38	0.63	3.50	7.64	0.059
		NS14	Trap 160+100	Cyl 60	60	260	38	0.63	4.33	10.56	0.077
		NS15	Trap 160+150	Cyl 60	60	310	38	0.63	5.17	11.18	0.146
		NS16	Trap 160+200	Cyl 60	60	360	38	0.63	6.00	13.37	0.173
		NS17	Trap 160+250	Cyl 60	60	410	38	0.63	6.83	12.89	0.224
		NS18	Trap 160+300	Cyl 60	60	460	38	0.63	7.67	14.02	0.209
		NS70	Trap320	Cyl 60	60	320	76	1.27	5.33	22.4	0.094
		NS71	Trap320+50	Cyl 60	60	370	76	1.27	6.17	28.84	0.122
		NS72	Trap 320+100	Cyl 60	60	420	76	1.27	7.00	35.27	0.142
		NS73	Trap 320+150	Cyl 60	60	470	76	1.27	7.83	39.84	0.167
		NS74	Trap 320+200	Cyl 60	60	520	76	1.27	8.67	44.15	0.197
		NS75	Trap 320+250	Cyl 60	60	570	76	1.27	9.50	46.16	0.241
	Dep/Dia	NS20	Trap 320/76	Cyl 114	114	320	76	0.67	2.81	33.65	0.084
		NS21	Trap 320/58	Cyl 114	114	320	58	0.51	2.81	30.35	0.090
		NS22	Trap 320/38	Cyl 114	114	320	38	0.33	2.81	20.22	0.098
		NS23	Trap 320/19	Cyl 114	114	320	19	0.17	2.81	9.14	0.141
		NS27	Trap 320/19	Cyl 60	60	320	19	0.32	5.33	4.45	0.174
		NS24	Trap 320/40	Cyl 60	60	320	40	0.67	5.33	12.22	0.102
		NS25	Trap 320/58	Cyl 60	60	320	58	0.97	5.33	19.51	0.095
		NS26	Trap 320/76	Cyl 60	60	320	76	1.27	5.33	23.76	0.094

Table C.1 Sand test conditions for vertical structures (continued).

Element	Parameter	Test	Keel Shape & size mm	Pier Shape & size mm	Pier Diameter mm	Keel width mm	Keel depth mm	Depth/diam	Wid/diam	Maximum force N	Dist. to max. F m
Structure	Shape	'01,20,f21,3	Trap 320	Cyl 114	114	320	76	0.67	2.81	35.3	0.094
		NS31	Contin 38	Cyl 114	114		38	0.33		31	0.354
		NS40	Trap 160	Sqa 114	114	160	38	0.33	1.40	7.8	0.032
		NS41	Trap 320	Sqa 114	114	320	76	0.67	2.81	32.74	0.095
		NS41a	Trap 320	Sqa 114	114	320	76	0.67	2.81	33.34	0.068
		NS42	Contin 38	Sqa 114	114		38	0.33		36.58	0.414
		NS43	Trap 160	Tria 114	114	160	38	0.33	1.40	7.52	0.121
		NS44	Trap 320	Tria 114	114	320	76	0.67	2.81	31.12	0.141
		NS45	Contin 38	Tria 114	114		38	0.33		26.1	0.430
		NS46	Trap 320	Tria 114	114	320	76	0.67	2.81	31.14	0.127
Effective width	Edge	NS50	Contin 38	Sqa 114	114		38	0.33		37.28	0.4016
		NS51	Contin 38	Sqa 114	114		38	0.33		36.89	
		NS52	Trap 320	Sqa 114	114	320	76	0.67	2.81	34.07	0.0803
		NS53	Trap 320	Flat 228	228	320	76	0.33	1.40	52.54	0.0732
		NS54	Contin 38	Flat 228	228		38	0.17		73.27	0.354
		NS55	Contin 38	Flat 228	228		38	0.17		76.9	
		NS56	Trap 320	Flat 228	228	320	76	0.33	1.40	49.44	0.732
		NS57	Trap 320	Flat 343	343	320	76	0.22	0.93	71.58	0.0612
		NS58	Contin 38	Flat 343	343		38	0.11		110.49	0.29
		NS59	Contin 38	Flat 343	343		38	0.11		109.3	
		NS60	Trap 320	Flat 343	343	320	76	0.22	0.93	65.1	0.0548

Table C.1 Sand test conditions for vertical structures (continued).

Development of local failure

Test	Keel Shape & size mm	Pier shape & size mm	Width or diam mm	Depth mm	Dep/diam	Dist. to measurement mm	Front breakout mm	Side breakout mm	Height fr cyl. base mm	Force N	Relative Surcharge Hsur	Relative F.Rupture r/D	Relative S.Rupture s/D	Relative Penetra. Dist/D
										0	0	0	0	0
NS30a	Contin 19	Cyl 114	114	19	0.17	74	50	25	39	5.919	0.18	0.44	0.22	0.65
		Cyl 114	114	19	0.17	124.8	60	36	50	7.333	0.27	0.53	0.32	1.09
		Cyl 114	114	19	0.17	174	68	48	57	8.025	0.33	0.60	0.42	1.53
		Cyl 114	114	19	0.17	224.9	70	54	59	8.82	0.35	0.61	0.47	1.97
		Cyl 114	114	19	0.17	277.5	75	58	61	9.02	0.37	0.66	0.51	2.43
		Cyl 114	114	19	0.17	326.6	80	60	61	9.93	0.37	0.70	0.53	2.86
		Cyl 114	114	19	0.17	375.7	82	62	62	9.44	0.38	0.72	0.54	3.30
		Cyl 114	114	19	0.17	426.6	80	62	61	9.44	0.37	0.70	0.54	3.74
		Cyl 114	114	19	0.17	474	82	65	61	9.81	0.37	0.72	0.57	4.16
NS31a	Contin 38									0	0.00	0.00	0.00	0.00
		Cyl 114	114	38	0.33	70.5	70	15	57	13.15	0.17	0.61	0.13	0.62
		Cyl 114	114	38	0.33	119.8	90	45	71	19.96	0.29	0.79	0.39	1.05
		Cyl 114	114	38	0.33	171.2	100	60	80	24.01	0.37	0.88	0.53	1.50
		Cyl 114	114	38	0.33	218.5	100	70	87	26.85	0.43	0.88	0.61	1.92
		Cyl 114	114	38	0.33	271.8	108	75	90	28.64	0.46	0.95	0.66	2.38
		Cyl 114	114	38	0.33	321.2	115	78	93	28.87	0.48	1.01	0.68	2.82
		Cyl 114	114	38	0.33	370.5	120	80	94	30.11	0.49	1.05	0.70	3.25
		Cyl 114	114	38	0.33	421.8	120	85	94	28.28	0.49	1.05	0.75	3.70
		Cyl 114	114	38	0.33	469.2	115	85	94	29.88	0.49	1.01	0.75	4.12
NS34a	Contin 40									0	0.00	0.00	0.00	0.00
		Cyl 60	60	36	0.60	56.9	50	25	51	8.056	0.25	0.83	0.42	0.95
		Cyl 60	60	40	0.67	106	78	45	66	12.1	0.43	1.30	0.75	1.77
		Cyl 60	60	40	0.67	156.9	85	50	75	14.72	0.58	1.42	0.83	2.62
		Cyl 60	60	40	0.67	206	85	56	79	15.94	0.65	1.42	0.93	3.43
		Cyl 60	60	40	0.67	258.6	85	60	81	16.27	0.68	1.42	1.00	4.31
		Cyl 60	60	40	0.67	307.8	90	65	83	18.63	0.72	1.50	1.08	5.13
		Cyl 60	60	40	0.67	356.9	90	67	84	17.57	0.73	1.50	1.12	5.95
		Cyl 60	60	40	0.67	406	90	67	84	15.87	0.73	1.50	1.12	6.77
		Cyl 60	60	40	0.67	456.9	90	68	83	16.75	0.72	1.50	1.13	7.62
		Cyl 60	60	40	0.67	506	91	68	83	16	0.72	1.52	1.13	8.43
NS36a	Contin 76									0	0.00	0.00	0.00	0.00
		Cyl 60	60	36	0.60	57.7	45	40	55	15.98	0.32	0.75	0.67	0.96
		Cyl 60	60	66	1.10	107.7	85	40	96	34.9	0.50	1.42	0.67	1.80
		Cyl 60	60	76	1.27	157.7	120	60	106	43.65	0.50	2.00	1.00	2.63
		Cyl 60	60	76	1.27	207.7	130	75	117	46.14	0.68	2.17	1.25	3.46
		Cyl 60	60	76	1.27	260.3	135	78	122	47.61	0.77	2.25	1.30	4.34
		Cyl 60	60	76	1.27	310.3	125	82	126	50.35	0.83	2.08	1.37	5.17
		Cyl 60	60	76	1.27	360.3	135	90	127	51.44	0.85	2.25	1.50	6.01
		Cyl 60	60	76	1.27	407.7	150	86	127	49.34	0.85	2.50	1.43	6.80
		Cyl 60	60	76	1.27	460.3	150	90	128	47.08	0.87	2.50	1.50	7.67

Table C.1 Sand test conditions for vertical structures (continued).

Development of local failure edge effects

Test	Keel Shape & size mm	Pier shape & size mm	Width or diam mm	Depth mm	Dep/diam	Dist. to measurement mm	Front breakout mm	Side breakout mm	Height fr cyl. base mm	Force N	Relative Surcharge Hsur	Relative F.Rupture r/D	Relative S.Rupture s/D	Relative Penetra. Dist/D
NS51	Contin 38									0	0.00	0.00	0.00	0.00
		Sqa 114	114	38	0.33	68	100	25	58	15.13	0.18	0.88	0.22	0.60
		Sqa 114	114	38	0.33	119.3	110	40	76	22.48	0.33	0.96	0.35	1.05
		Sqa 114	114	38	0.33	168.6	130	54	88	28.15	0.44	1.14	0.47	1.48
		Sqa 114	114	38	0.33	218	137	60	96	32.44	0.51	1.20	0.53	1.91
		Sqa 114	114	38	0.33	269.3	150	65	100	32.22	0.54	1.32	0.57	2.36
		Sqa 114	114	38	0.33	318.6	140	75	105	35.6	0.59	1.23	0.66	2.79
		Sqa 114	114	38	0.33	369.9	150	80	107	36.65	0.61	1.32	0.70	3.24
		Sqa 114	114	38	0.33	417.3	160	80	108	35.08	0.61	1.40	0.70	3.66
NS55	Contin 38	Flat 228	228	38	0.17	73.2	105	28	58	29.57	0.09	0.46	0.12	0.32
		Flat 228	228	38	0.17	120.6	160	40	75	39.56	0.16	0.70	0.18	0.53
		Flat 228	228	38	0.17	170.6	150	45	88	48.03	0.22	0.66	0.20	0.75
		Flat 228	228	38	0.17	220.6	185	60	98	58	0.26	0.81	0.26	0.97
		Flat 228	228	38	0.17	273.2	190	65	107	58.59	0.30	0.83	0.29	1.20
		Flat 228	228	38	0.17	323.2	190	65	116	69.08	0.34	0.83	0.29	1.42
		Flat 228	228	38	0.17	373.2	195	80	123	75.95	0.37	0.86	0.35	1.64
NS59	Contin 38	Flat 343	343	38	0.11	70.6	105	30	56	42.59	0.05	0.31	0.09	0.21
		Flat 343	343	38	0.11	123.2	135	40	64	64.51	0.08	0.39	0.12	0.36
		Flat 343	343	38	0.11	172.3	180	55	76	77.92	0.11	0.52	0.16	0.50
		Flat 343	343	38	0.11	221.5	170	60	85	85.4	0.14	0.50	0.17	0.65
		Flat 343	343	38	0.11	274.1	185	70	96	107.24	0.17	0.54	0.20	0.80
		Flat 343	343	38	0.11	323.2	245	75	102	107.91	0.19	0.71	0.22	0.94

Continuous Layer local failure

Test	Keel Shape & size mm	Pier Shape & size mm	Pier diameter mm	Keel depth mm	Depth/D	Dist-steady force m	Front breakout mm	Side breakout mm	Height fr cyl. base mm	Max F N	Relative surcharge Hsur	Relative F.rupture r/Dia	Relative S.rupture s/Dia	Relative penetra. Dist/D
NS30	Contin 19	Cyl 114	114	19	0.17	285.1	82	62	61	9.85	0.37	0.72	0.54	2.50
NS30a	Contin 19	Cyl 114	114	19	0.17	300.2	82	62	61	11.79	0.37	0.72	0.54	2.63
NS31	Contin 38	Cyl 114	114	38	0.33	354.1	117	80	94	31.99	0.49	1.03	0.70	3.11
NS31a	Contin 38	Cyl 114	114	38	0.33	295.36	117	80	94	30.33	0.49	1.03	0.70	2.59
NS32	Contin 58	Cyl 114	114	58	0.51	343.7	140	105	121	60.64	0.55	1.23	0.92	3.01
NS33	Contin 76	Cyl 114	114	76	0.67	433.3	180	110	144	98	0.60	1.58	0.96	3.80
NS34	Contin 40	Cyl 60	60	40	0.67	277.7	90	67	84	17.37	0.73	1.50	1.12	4.63
NS34a	Contin 40	Cyl 60	60	40	0.67	295	90	67	84	18.93	0.73	1.50	1.12	4.92
NS35	Contin 58	Cyl 60	60	58	0.97	400.3				33.06				6.67
NS36	Contin 76	Cyl 60	60	76	1.27	364.2	150	90	127	51.67	0.85	2.50	1.50	6.07
NS36a	Contin 76	Cyl 60	60	76	1.27	339.22	150	90	127	52.36	0.85	2.50	1.50	5.65

Table C.2 Sand test conditions for conical structures.

	Notes	Test	Diameter cone base Db mm	Keel width W mm	Keel depth H mm	Average diameter Dav mm	H/Dav	W/Dav	Maximum force N	Dist. to max. F m	P/Dav
Repeat tests	trap 320	con01.dat	255	320	76	203	0.374	1.575	36.4	0.165	0.812
	trap 320	con02.dat	255	320	76	203	0.374	1.575	37.3	0.184	0.905
	trap 320	con03.dat	255	320	76	203	0.374	1.575	34.9	0.157	0.774
	trap 320	con04.dat	255	320	76	203	0.374	1.575	36.5	0.179	0.881
	trap 320	con05.dat	255	320	76	203	0.374	1.575	35.8	0.154	0.759
	trap 320	con10.dat	255	320	76	203	0.374	1.575	36.6	0.147	0.724
	AVERAGE		255	320	76	203	0.374	1.575	36.2	0.164	0.809
Keel Shape	tri 320	con06.dat	255	320	94	191	0.492	1.676	35.9	0.127	0.664
	sin 320	con07.dat	255	320	74	205	0.362	1.565	37.1	0.155	0.756
	trap 460	con08.dat	255	462	58	215	0.269	2.144	32.6	0.227	1.052
	tri 460	con09.dat	255	462	65	211	0.309	2.193	36.0	0.229	1.086

Penet to Peak Force	width	con24.dat	255	244	76	203	0.374	1.201	23.9	0.148	0.729
		con21.dat	255	370	76	203	0.374	1.821	48.3	0.201	0.989
		con22.dat	255	420	76	203	0.374	2.067	55.2	0.192	0.944
		con23.dat	255	470	76	203	0.374	2.313	66.7	0.235	1.158
	depth	con30.dat	255	320	54	218	0.248	1.467	32.0	0.149	0.684
		con31.dat	255	320	34	232	0.147	1.380	21.8	0.181	0.782
		con32.dat	255	320	16	244	0.066	1.311	11.6	0.201	0.823

Table C.2 Sand test conditions for conical structures (continued).

Continuous indentation

(all measures are 4 mm high due to model placement)

	Cone Db mm	Width W	Depth H mm	H/Db	Dist. to measure. cm	Keel penetra. mm	Force N	r0 mm	r45 mm	r90 mm	H0 top mm	H0 cone mm	H45 mm	H90 mm
con50.dat	255	contin	0	0	0.0	-13	0.4	97.5	97.5	97.5	0	0	0	0
	255	contin	43.42842	0.170	8.2	70	17.9	120	115	97.5	42	42	22	0
	255	contin	74.29697	0.291	13.2	119	41.4	190	145	97.5	92	70	55	0
	255	contin	76	0.298	18.1	168	61.1	210	175	135	110	91	80	41
	255	contin	76	0.298	23.0	218	71.0	240	185	140	125	110	100	70
	255	contin	76	0.298	28.6	273	82.2	230	200	150	140	125	120	86
	255	contin	76	0.298	33.6	323	86.9	240	205	165	148	136	130	102
	255	contin	76	0.298	38.5	372	90.7	245	210	165	154	147	140	110
	255	contin	76	0.298	43.4	422	92.6	245	215	170	158	153	140	115

	Cone Db mm	Width W	Depth H mm	H/Db	Dist. to measure. cm	Keel penetra. mm	Force N	r0 mm	r45 mm	r90 mm	H0 top mm	H0 cone mm	H45 mm	H90 mm
con51.dat	255	contin	0	0.000	0.0	-5	0.3	97.5	97.5	97.5	0	0	0	0
	255	contin	44.55318	0.175	7.6	71	16.4	175	112	97.5	42	42	30	0
	255	contin	51	0.200	12.9	124	28.0	180	160	115	80	65	56	10
	255	contin	51	0.200	17.6	171	38.3	190	180	135	94	83	76	41
	255	contin	51	0.200	22.9	224	45.2	200	180	155	108	99	91	62
	255	contin	51	0.200	27.9	274	49.3	210	188	155	128	110	104	76
	255	contin	51	0.200	41.3	408	53.4	230	200	180	132	128	120	95
	255	contin	51	0.200	46.3	458	55.2	230	205	180	133	130	122	99

	Cone Db mm	Width W	Depth H mm	H/Db	Dist. to measure. cm	Keel penetra. mm	Force N	r0 mm	r45 mm	r90 mm	H0 top mm	H0 cone mm	H45 mm	H90 mm
con52.dat	255	contin	0	0.000	0.0	-7	0.0	97.5	97.5	97.5	0	0	0	0
	255	contin	26	0.102	7.7	70	7.8	145	135	97.5	41	31	20	0
	255	contin	26	0.102	13.0	123	14.1	160	150	97.5	60	51	45	0
	255	contin	26	0.102	17.9	172	18.6	170	160	112	71	67	60	29
	255	contin	26	0.102	23.2	225	21.5	170	165	138	81	79	71	45
	255	contin	26	0.102	28.1	274	20.7	175	165	140	90	86	80	55
	255	contin	26	0.102	33.2	325	24.5	180	175	150	95	90	84	60
	255	contin	26	0.102	45.1	444	24.7	187	180	160	100	98	90	65
	255	contin	26	0.102	44.9	442	25.0							

APPENDIX D

Curve fitting for measured quantities

An equation was required which could describe in closed-form the shape of the "length measurement" versus penetration curve for the structure indentation experiments in sand. The length measurements include the side and frontal rupture distances and the surcharge height (force traces were also of the same form). The boundary conditions required to fit the observed trends were:

$$\begin{aligned} P_{en} &= 0 \rightarrow Y = 0 \\ P_{en} &\Rightarrow \infty \rightarrow Y = constant \end{aligned} \qquad \textbf{(D.1)}$$

where P_{en} is penetration from initial contact and Y is the measured length quantity as a function of P_{en}. Also, at zero penetration the curve is observed to be tangent to the $Y = 0$ line.

A geometric curve which meets these criteria is of the form:

$$Y = Amp \frac{x^2}{\left(x^2 + \left[\frac{Amp^2}{PP} - Amp^2 \right] \right)} \qquad \textbf{(D.2)}$$

where *Amp* is the amplitude of the maximum asymptote line. The height of the curve at a penetration equal to *Amp* is *PP* times *Amp*. Thus *PP* defines the gradient or rate at which the curve approaches the upper asymptote.

While conducting regression analyses of the sand test results a form of the above equation was found to fit force, surcharge, and rupture distance data better than any other. It was of the form:

$$Y = C_a Amp^{C_b} \left[\frac{x^2}{x^2+Amp} \right]^{C_c} \tag{D.3}$$

where the constants C_a, C_b and C_c were determined analytically. This equation is analogous to the pure geometric form above and retains all boundary condition qualities. Figures D.1 and D.2 illustrate the performance of the above equations for curve fitting. Arbitrarily selected for this study was an experiment in which a 114 mm diameter cylinder indented a 38 mm deep sand layer (the sand was inclined at 32° at the front). In Figure D.1 the geometric formula (Equation D.2) was fitted using trial and error. All three measured data sets, frontal rupture distance, side rupture distance and surcharge height, were studied and show strong agreement with the curve form. In Figure D.2 the formulas determined using regression analysis were applied. The quality of fit for these traces is as good as or better than the trial and error fit confirming the that the regression curve fitting procedure is a valid one.

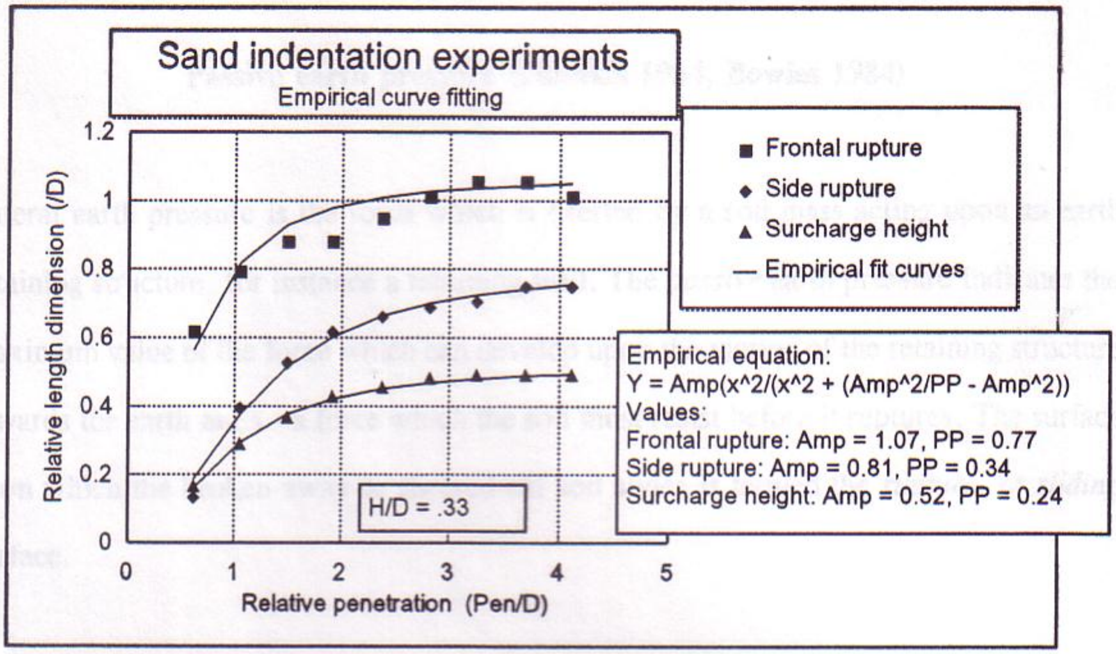


Figure D.1 Curve fitting using basic geometric formula.

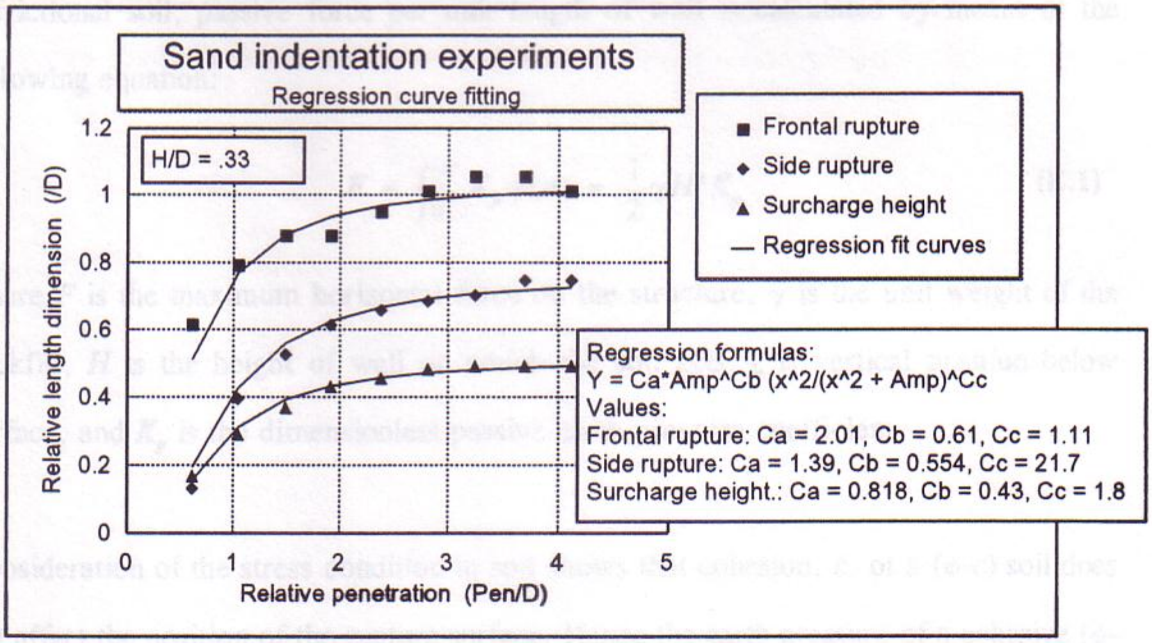


Figure D.2 Curve fitting using regression analysis.

Appendix E

Passive earth pressure (Jumikis 1984, Bowles 1984)

Lateral earth pressure is the force which is exerted by a soil mass acting upon an earth retaining structure, for instance a retaining wall. The *passive* earth pressure indicates the maximum value of the force which can develop upon the motion of the retaining structure towards the earth mass - a force which the soil must resist before it ruptures. The surface upon which the broken-away or sheared off soil slides is termed the *rupture*, or *sliding* surface.

The magnitude of passive earth pressure can be solved graphically or determined analytically using Coulomb's earth pressure theory. According to Coulomb's theory for a frictional soil, passive force per unit length of wall is calculated by means of the following equation:

$$F = \int_0^H K_p \gamma z dz = \frac{1}{2}\gamma H^2 K_p \qquad \text{(E.1)}$$

where F is the maximum horizontal force on the structure, γ is the unit weight of the backfill, H is the height of wall on which the soil acts, z is vertical position below surface, and K_p is the dimensionless passive earth pressure coefficient.

Consideration of the stress condition in soil shows that cohesion, c, of a (ϕ-c) soil does not affect the position of the rupture surface. Hence the earth pressure of a cohesive (ϕ-c) soil can be approximately determined by the method used for non-cohesive soils. On this basis the total passive pressure F of a ϕ-c soil per unit length is

$$F = \frac{1}{2}\gamma H^2 K_p + 2cH\sqrt{K_p} \tag{E.2}$$

When a uniform surcharge acts on the soil backfill the effect is taken care of analytically by modifying the unit weight of soil ($\gamma_{new} = \gamma_{old} + \gamma_{sur}$).

For earth pressure systems where the structure is sloped and there is a non-zero soil-structure friction angle, the solution for K_p may be determined by a static equilibrium of the forces acting on the ruptured soil wedge as shown in Figure E.1. The system of two equations for calculating the unknowns ω (rupture angle) and F is

$$F = \left[w \frac{\sin(\omega+\phi)}{\sin(\xi+\omega+\phi)} \right]_{\min} \qquad \frac{dF}{d\omega} = 0 \tag{E.3}$$

where ϕ is the soil internal friction angle, ϕ_1 is the soil-structure friction angle, α is the structure slope from vertical, $\xi = 90° - \alpha + \phi_1$ and w is the weight of the soil wedge:

$$w = \frac{1}{2}\gamma H^2 \left[\frac{\cos(\delta-\alpha)}{\cos^2\alpha} \right] \left[\frac{\cos(\omega-\alpha)}{\sin(\omega-\delta)} \right] \tag{E.4}$$

where δ is the slope of the soil surface. Jumikis (1984) has determined a general closed-form solution for this two equation system which yields:

$$K_p = \frac{\cos^2(\phi+\alpha)}{\cos^2\alpha\cos(\alpha-\phi_1)\left[1-\sqrt{\dfrac{\sin(\phi+\phi_1)\sin(\phi+\delta)}{\cos(\alpha-\phi_1)\cos(\delta-\alpha)}}\right]^2} \tag{E.5}$$

and reduces to the more familiar form of K_p for vertical frictionless structures in level soil:

$$K_p = \frac{1 + \sin\phi}{1 - \sin\phi} = \tan^2\left[\frac{\pi}{4} + \frac{\phi}{2}\right] \tag{E.6}$$

In cases where backfill is sloped in a discontinuous or curved manner a solution for K_p may be found by a lengthy graphical plotting procedure. Otherwise an approximation of the would-be linear slope, δ, that preserves the weight of the mobilized soil block (w) and the height of the soil at the wall (H_{sur}) has been approximated (in the formulation for K_p above, δ only influences w in the force equilibrium). In the vertical structure case where the slope was discontinuous as shown in Figure E.2, the slope approximation was determined as

$$\delta = atan\left[\frac{H_{sur}}{2r}\right] \tag{E.7}$$

In the sloping (conical) structure case where backfill was sloped in the form of a cosine curve as shown in Figure E.3 the slope was approximated as

$$\delta = atan\left[\frac{H_{sur}}{m4/\pi}\right] \tag{E.8}$$

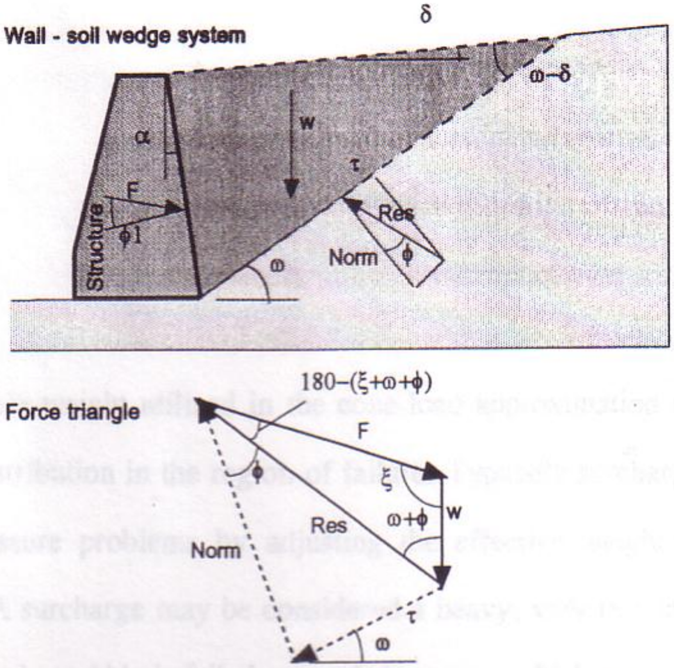
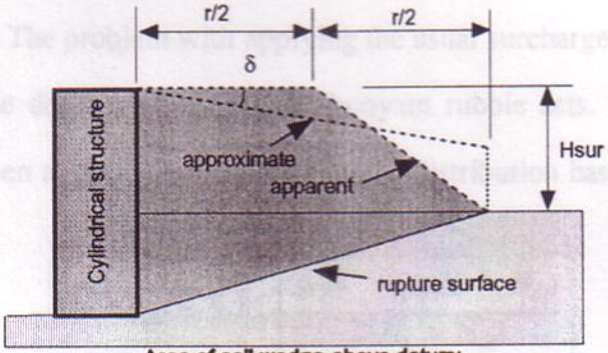
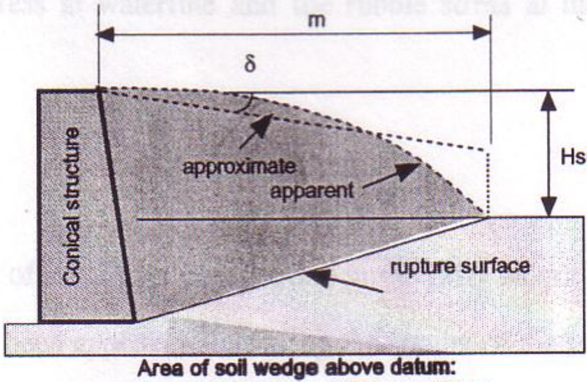


Figure E.1 Force equilibrium for passive earth pressure (Jumikis, 1984).



Area of soil wedge above datum:
Area = (r/2*Hsur + r/4*Hsur) = 3/4(1/2*2r*Hsur)

Figure E.2 Surface slope approximation for vertical structure indentation.



Area of soil wedge above datum:
Area = 2mHsur/ π = 1/2*(4m/π)*Hsur

Figure E.3 Surface slope approximation for conical structure indentation.

Appendix F

Cone force model notes

Effective weight

The effective rubble weight utilized in the cone load approximation model reflects the probable stress distribution in the region of failure. Typically surcharge is dealt with in passive earth pressure problems by adjusting the effective weight of the soil mass (Jumikis, 1984). A surcharge may be considered a heavy, very thin layer of soil on top of soil body. When ice rubble is failed upwards by a cone which extends below the water the submerged rubble effect is analogous to adding a negative surcharge to the base of the rubble layer. The problem with applying the usual surcharge correction is that it does not recognise the depth over which the buoyant rubble acts. As a result an alternate technique has been applied. An effective stress distribution has been assumed where

$$\gamma_{eff} = 9.81 \left[\frac{\rho_s H_s + \rho_k (H - H_{wl})}{2(H_s + H_{wl})} \right] \tag{F.1}$$

representing a linear distribution which has a maximum stress equal to the average of the maximum sail stress at waterline and the rubble stress at the cone base as shown in Figure F.1.

Sail geometry

The development of surcharge on the cone in the IMD laboratory (described in Chapter 6, Section 2) has been approximated using the results of the sand tests. In the sand tests trapezoidal sails were indented. The developed surcharge height was modelled analytically with great success using regression techniques with a preselected geometric equation (Appendix D). Thus the sails in the IMD tests have been analytically transformed to a trapezoidal shape which preserves the original sail width and area but adjusts the height. This is reflected in Figure F.2. Note that the trapezoidal sail approximation is used for the computation of cone surcharge height only.

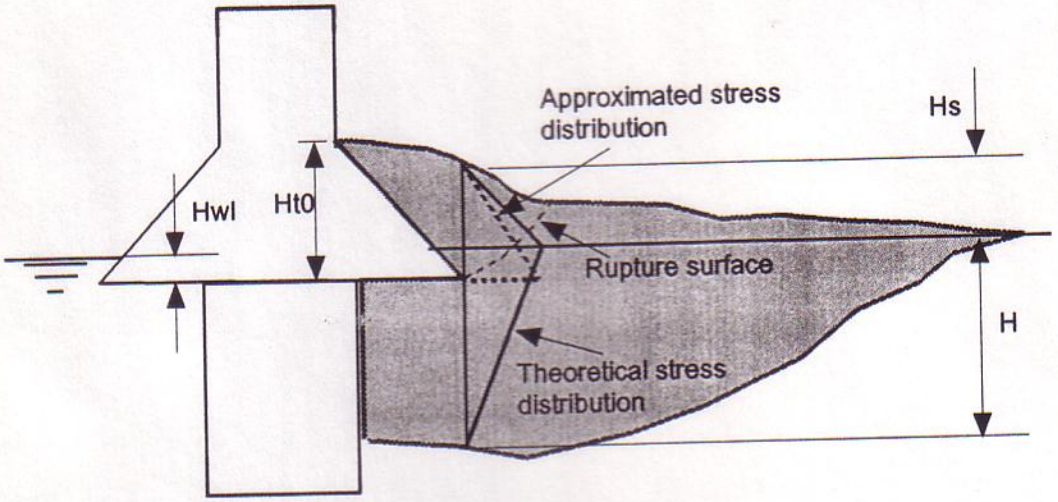


Figure F.1 Effective weight of rubble for cone force model.

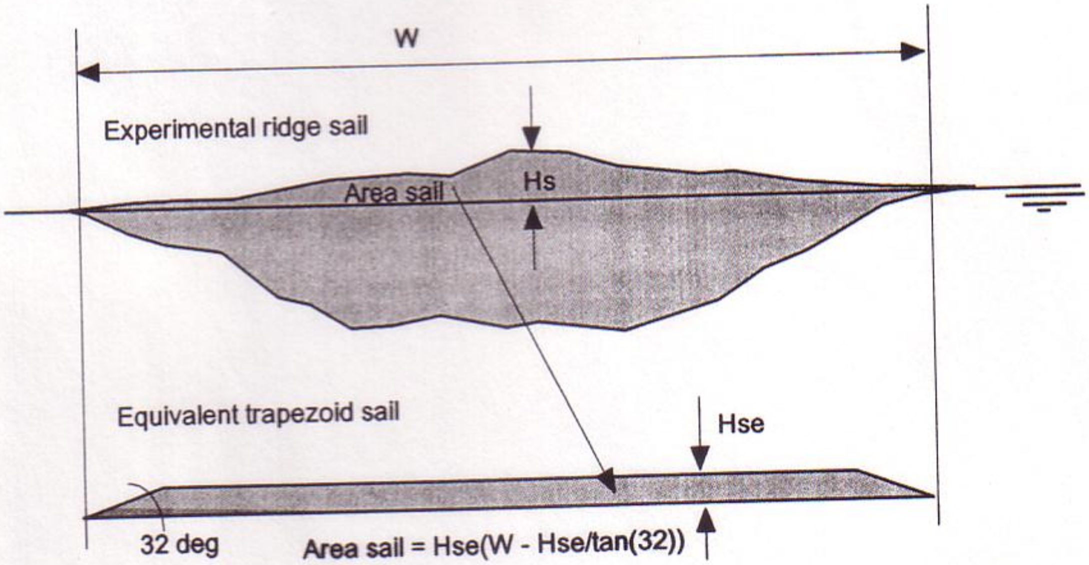


Figure F.2 Trapezoidal sail approximation.