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Violent breaking-wave impacts. Part 4: A detailed analysis and comparison of field and 1:4 scale measurements on sloping and vertical walls including the influence of air and scale effects.

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DATA USED IN 'VIOLENT BREAKING-WAVE IMPACTS. PART 4'.

FIELD DATA

Pmax (kPa) & tre (ms) values for low (L) & high (H) aeration impacts.

LPmax=[745.01 515.32 398.80 336.57 269.41 262.43 249.8 217.69 204.74 189.31 181.52 110.31 109.80]

Ltre=[1.8 1.5 3.0 2.1 1.1 0.5 4.2 0.6 4.3 7.7 3.3 2.9 1.2]

LPmaxc=[192.89 153.36] Treat with caution. Discussed in text.

Ltrec=[12.8 10.0]

Lpmax=[268.5 221.7] LA pmax values.

Ltrep=[17.9 1.6]

HPmax=[401.50 348.29 305.53 249.77 200.92 199.52 188.22]

Htre=[0.9 4.1 0.8 4.6 2.0 2.7 3.5]

HPmaxc=[770.59 223.64 119.63] Treat with caution. Discussed in text.

Htrec=[30.6 13.0 32.2]

Hpmax=[113.9 184.3 102.8] HA pmax values.

Htrep=[26.6 13.6 1.2]

Fall times

tf1* values:

LPmaxtf1s=[745.0 269.4 217.7 192.9 181.5]

Ltf1s=[1.2 45.4 5.7 13.3 29.5]

HPmaxtf1s=[401.5 249.8 223.6 200.9 199.5 188.2 119.6]

Htf1s=[83.0 25.0 53.0 22.2 56.5 136.0 15.8]

tf1 values:

Ltf1=[25.5 24.0 28.7 26.1 185 3.7 163.6 17.0 22.2 178 32.2 220.8 70.8 112.5 25.7]

Htf1=[25.4 201 117 47.0 109 280 107 211 625 269]

tf2 values:

Ltf2=[110 210 170 192 520 258 402 196 252 428 228 302 415 213 159]

Htf2=[517 994 695 138 692 592 915 699 1103 553]

Variation of Pmax with PQHmsx for both LA & HA events

LPmax=[745.01 515.32 398.80 336.57 269.41 262.43 249.84 217.69 204.74 192.89 189.31 181.52 153.36 110.31 109.80]

LPQHmax=[8.6 15.1 12.8 26.7 37.0 5.5 17.7 4.3 4.8 10.8 14.3 12.1 21.9 5.8 8.6]

HPmax=[770.59 401.50 348.29 305.53 249.77 223.64 200.92 199.52 188.22 119.63]

HPQHmax=[17.7 12.7 15.8 21.2 8.1 6.8 11.9 8.7 18.0 76.8]

Maximum pressures (kPa) measured by PAU3, PAU7 and PAU8.

Distance 3-7 = 1.7m distance 3-8 = 3.1m

Low aeration values (PAU 7 & 8 not working in L1, L5, L11 & L14):

PAU3L=[84.93 24.83 336.57 7.98 230.01 29.75 138.81 57.35 88.82 71.11 110.31]
PAU7L=[59.96 32.49 132.35 9.44 94.84 18.83 145.01 35.80 69.23 43.80 19.12]
PAU8L=[52.27 12.98 116.25 4.43 82.01 5.65 20.75 59.20 31.67 72.30 11.53]

High aeration values:

PAU3H=[47.00 189.90 146.47 163.52 184.28 194.87 200.92 199.52 42.42 119.63]
PAU7H=[41.89 61.98 34.28 87.41 185.81 288.41 66.57 82.64 50.07 77.61]
PAU8H=[25.57 21.80 26.34 26.90 46.25 189.97 22.72 49.19 52.79 29.42]

Pressure impulses IP (kPa.s) and their durations tre+tf1 & tre+f2 (ms)

Low aeration:

LIPref1=[3.14 2.17 2.68 2.30 4.84 0.30 10.57 0.54 1.69 7.91 1.89 12.73 4.16
2.78 0.84]
Ltref1=[27.3 25.5 31.7 28.2 186.1 4.2 167.8 17.6 26.5 190.8 40.9 224.1 80.8
115.4 26.9]

LIPref2=[7.39 7.59 5.59 9.53 9.41 2.92 17.42 3.13 5.99 12.77 6.31 14.50
17.29 3.56 2.43]
Ltref2=[111.8 211.5 173.0 194.1 521.1 258.5 406.2 196.6 256.3 440.8 235.7 395.3
425.0 215.9 160.2]

High aeration:

HIPref1=[10.90 13.57 8.02 4.03 6.62 10.34 3.17 10.33 8.90 7.91]
Htref1=[56.0 201.9 212.1 47.8 136.6 293.0 109.0 213.7 139.5 301.2]
HIPref2=[21.18 24.55 17.38 7.41 15.72 14.06 11.23 16.49 31.97 9.40]
Htref2=[547.6 994.9 699.1 138.8 696.6 605.0 917.0 701.7 1106.5 585.2]

Fmax (kN/m) values for low (L) & high (H) aeration impacts.

LFmax=[714.86 513.14 400.66 413.01 271.01 261.55 369.23 215.19 312.33 194.44
215.04 211.23 210.49 128.20 118.23]

HFmax=[775.08 382.98 346.76 305.24 253.50 414.09 263.23 368.11 278.71 140.27]

Force impulses IF (kN.s/m) and their durations tre+tf1 & tre+f2 (ms)

Low aeration:

LIFref1=[7.41 2.15 2.73 41.54 17.78 0.30 47.04 0.53 25.25 7.10 7.32 33.78
59.27 9.81 3.39]
LIFtref1=[59.1 25.5 34.5 240.3 235.4 4.5 300.3 17.9 271.0 154.7 91.7 317.5
491.1 201.9 122.5]

LIFref2=[48.97 22.98 21.11 87.63 37.47 2.98 59.46 13.01 44.11 61.82 41.53 48.03
91.62 27.71 23.43];
LFtref2=[258.8 252.5 280.0 472.0 519.4 257.5 421.3 312.6 463.3 1258.7 432.9 516.5
938.1 594.9 593.7]

High aeration:

HIFref1=[21.84 52.71 52.14 59.93 38.63 52.46 48.00 70.77 83.92 25.22]
HFTref1=[180.7 507.8 522.1 652.8 437.7 364.2 522.4 509.6 669.3 335.9]

HIFref2=[57.45 79.65 66.80 59.97 56.25 80.35 81.87 98.24 128.83 44.11]
HFTref2=[681.7 1237.8 922.1 653.8 770.7 762.2 1334.4 990.6 1420.3 890.9]

Aeration levels

Estimated at around the time of Pmax

Low-aeration impacts:

Pmax values:

LPmax=[745.01 515.32 398.80 336.57 269.41 262.43 249.84 217.69 204.74 192.89
189.31 153.36 109.80]

Voids % at Pmax as measured

LVPmax=[2.99 6.06 4.86 10.14 1.77 7.16 14.34 7.19 15.21 28.89 8.07 28.53 2.89]

High-aeration impacts:

Pmax values:

HPmax=[770.59 348.29 249.77 223.64 288 200.92 199.52 188.22 119.63]

Voids % at Pmax as measured

HVPmax=[6.94 8.44 19.84 11.41 11.47 41.29 15.74 24.92 8.07]

Average at around the time of PQHmax for PAUs 1, 2 & 3 which are 4.5m, 5.5m & 6.2m above CD. B = % voids ratio & P = average pressure in kPa.

Low-aeration average B% and average pressure at PAU1, PAU2 & PAU3:

LB1=[8.04 7.87 2.75 8.60 11.56 8.91 7.28 11.75 13.73 9.91]
LP1=[12.39 12.27 36.35 7.49 16.20 4.44 11.28 10.13 20.49 12.25]

LB2=[7.08 19.98 15.72 4.94 16.82 31.12 14.20 28.43 12.96 19.70 12.79 14.98 18.95
7.56]

LP2=[18.34 9.34 9.47 36.60 15.83 3.00 14.83 5.01 9.27 7.59 24.03 17.10 9.33
16.17]

LB3=[8.54 20.87 25.00 8.48 8.70 39.30 16.93 34.72 22.14 18.95 9.82 18.24 25.30
7.16]

LP3=[8.67 5.49 5.87 24.49 8.07 1.70 9.60 3.03 5.58 4.75 14.26 12.73 5.73
8.07]

High-aeration average B% and average pressure at PAU1, PAU2 & PAU3:

HB1=[6.17 15.76 8.69 8.17 6.64 8.75 7.97 7.69 15.05]
HP1=[15.32 13.85 13.69 9.96 18.08 19.69 14.37 18.41 13.73]

HB2=[8.59 19.06 14.21 17.98 9.93 17.16 12.22 9.69 17.62]
HP2=[12.62 10.88 8.86 7.60 14.80 14.71 11.97 16.78 10.65]

HB3=[12.89 21.32 28.06 14.07 14.75 20.87 14.66 11.22 21.72]
HP3=[8.54 6.36 3.24 5.22 10.00 8.29 8.44 11.55 6.59]

ERC oscillations in HA impacts

E1 & RC1 p(t) values (kPa):

E1= [-75.4 40.2 3.8 47.2 22.6 1.7 21.7 9.6 8.4 -0.7]
RC1=[78.2 70.1 45.9 74.0 43.9 16.8 55.5 25.6 31.0 5.5]

Period (To ms), Damping Ratio (ξ) & Log. Dec. (LD) of p(t)

Before a discontinuity:

pTo=[142.0 80.0 220.0 32.8 107.8 271.0 38.8 117.8]
pxi=[0.310 0.340 0.110 0.025 0.140 0.120 0.050 0.110]
pLD=[2.049 2.272 0.695 0.157 0.888 0.759 0.315 0.695]

After discontinuity:

pTo=[114.0 182.0 104.1 212.0 95.7]
pxi=[0.020 0.090 0.068 0.027 0.047]
pLD=[0.126 0.568 0.428 0.170 0.296]

No discontinuity:

pTo=[242.3 114.1]
pxi=[0.082 0.055]
pLD=[0.517 0.346]

Period (To ms), Damping Ratio (ξ) & Log. Dec. (LD) of f(t)

Before a discontinuity:

fTo=[116.6 271.0 72.0]
fxi=[0.153 0.100 0.08]
fLD=[0.97 0.631 0.113]

After discontinuity:

fTo=[101.4 227.8 218.0]
fxi=[0.035 0.024 0.025]
fLD=[0.220 0.151 0.157]

No discontinuity:

fTo=[173.1 155.0 107.5 99.5 242.3 115.4]
fxi=[0.055 0.116 0.095 0.005 0.085 0.074]
fLD=[0.321 0.734 0.600 0.028 0.536 0.466]

GWK SLOPING-WALL DATA

Pmax (kPa) & tre (ms) values listed as low (L) and high (H) aeration in model terms

PAU measurements:

PAULPmax=[55.73 276.34 116.15 150.24 71.33 196.01 61.68 32.53 47.04 183.32 67.28]
PAULtre=[0.97 0.33 0.46 0.80 8.45 0.35 12.48 0.74 1.20 4.49 15.80]

PAUHPmax=[60.15 100.03 92.85 150.26 87.66 66.43 172.83 793.35 269.87 83.53 140.27
98.31 51.74 129.32 27.51 84.48 50.87]

PAUhtre=[21.04 8.80 38.54 1.57 42.36 11.81 19.44 0.65 10.91 9.44 5.19 32.37 31.34
5.38 31.42 38.40 0.42]

FZK measurements:

FZKLPmax=[400.42 206.07 120.30 121.24 588.43 298.36 184.37 117.28 33.90 42.92
327.97 74.69 36.08 52.57 35.53 28.72 98.67 35.28 126.02 29.71 37.12]

FZKLtre=[0.77 3.59 3.18 4.93 0.19 0.38 14.61 8.65 25.76 19.48 0.91 6.71 6.72 3.21
4.99 15.80 5.55 9.74 1.33 2.59 15.63]

FZKHPmax=[106.15 113.64 107.39 59.19 59.85 43.37 253.50 69.06 75.49]

FZKHtre=[5.83 11.72 15.78 30.44 32.58 7.56 13.85 10.33 42.62]

Fall times (ms) from Pmax (kPa) as estimated from model data

tf1* LA PAU & FZK:

PAULPmaxtf1s=[116.15 71.33 196.01 32.53]
PAULtf1s=[0.2 115.4 1.8 4.1]

FZKLPmaxtf1s=[588.43 184.37 327.97 74.69 28.72 98.67 126.02 29.72 37.12]
FZKLtf1s=[9.1 3.3 5.4 3.5 4.7 39.5 9.0 4.8 28.0]

tf1* HA PAU & FZK:

PAUHPmaxtf1s=[60.15 92.85 150.26 87.66 172.83 793.35 269.87 83.53 140.27 84.48
50.87]

PAUhtf1s=[12.4 36.6 1.3 28.3 17.8 15.7 16.5 18.1 16.8 22.3 3.0]

FZKHPmaxtf1s=[113.64 59.19]

FZKHtf1s=[55.1 50.5]

tf1 LA PAU & FZK:

PAULPmax=[55.73 276.34 116.15 150.24 71.33 196.01 61.68 32.53 47.04 183.32 67.28]
PAULtf1=[0.6 0.6 31.2 50.1 172.3 24.0 56.9 9.4 9.8 11.5 13.2]

FZKLPmax=[400.42 206.07 120.30 121.24 588.43 298.36 184.37 117.28 33.90 42.92
327.97 74.69 36.08 52.57 35.53 28.72 98.67 35.28 126.02 29.71 37.12]

FZKLtf1=[6.9 25.4 38.8 16.8 18.0 23.2 48.8 11.7 50.2 64.6 7.6 35.2 5.8 5.5 15.8
15.7 49.0 11.1 39.0 54.1 65.7]

tf1 HA PAU & FZK:

PAUHPmax=[60.15 100.03 92.85 150.26 87.66 66.43 172.83 793.35 269.87 83.53 140.27
98.31 51.74 129.32 27.51 84.48 50.87]

PAUHTf1=[39.9 46.6 89.2 17.3 88.2 148.5 59.1 53.3 52.9 61.5 45.0 34.9 17.3 24.2
29.6 55.5 18.1]

FZKHPmax=[106.15 113.64 107.39 59.19 43.37 253.50 69.06 75.49]

FZKHTf1=[52.2 107.8 19.4 131.9 35.9 12.0 29.5 39.3]

tf2 LA PAU & FZK (PFLPmaxP2fs are as for tf1):

PAULTf2=[4.4 32.6 89.9 354.5 286.1 95.4 403.6 79.9 119.2 38.0 185.8]

FZKLTf2=[48.1 58.6 77.6 51.5 67.4 50.5 141.3 92.8 117.8 328.8 32.9 113.9 14.1 58.3
305.0 47.0 105.7 52.2 99.8 106.7 94.8]

tf2 HA PAU & FZK (PFHPmaxP2fs are as for tf1):

PAUHTf2=[113.2 353.9 283.3 140.9 278.2 543.3 151.2 202.0 189.3 179.5 165.1 179.8
151.6 112.1 176.3 177.7 143.8]

FZKHTf2=[52.2 107.8 19.4 131.9 35.9 12.0 29.5 39.3]

Maximum pressures (kPa) measured by PAU2 and FZK4

Distance in the GWK between PAU2 & FZK4 = 0.94m. The same event may not be of the same type. The model results are more scattered than the field and contain two extreme PAU values. This may be because there are twice as many values. Pressures are as measured where L= both LA, H = both HA and B = one LA and the other HA.

PAU2L=[79.49 4.62]

FZK4L=[120.31 6.20]

PAU2H=[86.67 87.46 70.77 16.28 11.00]

FZK4H=[106.15 113.64 42.14 43.37 24.96]

PAU2B=[60.15 150.26 793.35 140.29 27.35 129.32 31.14 7.91 50.87]

FZK4B=[50.18 206.07 414.75 68.10 54.23 33.90 34.83 12.82 26.07]

Variation of Pmax with PQHmsx for both LA & HA events

PAULPmax=[55.73 276.34 116.15 150.24 71.33 196.01 61.68 32.53 47.04 183.32 67.28]

PAULPQHmax=[6.46 14.70 12.70 11.74 15.47 12.90 8.12 2.63 4.79 5.74 4.06]

PAUHPmax=[60.15 100.03 92.85 150.26 87.66 66.43 172.83 793.35 269.87 83.53 140.27
98.31 51.74 129.32 27.51 84.48 50.87]

PAUHPQHmax=[12.51 17.5 17.45 7.60 8.10 10.00 10.80 9.96 14.04 5.51 11.80 12.71
6.51 4.92 5.78 10.40 3.52]

FZKLPmax=[400.42 206.07 120.30 121.24 588.43 298.36 184.37 117.28 33.90 42.92
327.97 74.69 36.08 52.57 35.53 28.72 98.67 35.28 126.02 29.71 37.12]
FZKLPQHmax=[8.68 7.40 7.20 9.39 10.50 9.52 9.26 9.08 4.14 7.97 5.29 5.29 3.43
3.28 2.45 3.28 8.22 5.24 3.75 4.88 5.90]

FZKHPmaxP=[106.15 113.64 107.39 59.19 59.85 43.37 253.50 69.06 75.49]
FZKHPQHmax=[10.60 11.10 7.11 12.50 12.50 2.94 4.17 7.76 4.34]

BM law scaled values of Pmax & tre

PAUHPmaxBM=[162.82 319.65 288.48 573.91 266.75 184.88 708.64 8644.25 1428.65
249.94 518.31 312.07 134.80 460.23 63.73 253.78 132.00]
PAUhtreBM=[67.11 24.58 110.19 3.76 123.18 36.87 43.62 0.50 19.01
27.83 12.82 90.93 102.94 13.71 112.74 112.83 1.39]
FZKHPmaxBM=[347.24 382.30 352.95 159.53 161.77 108.64 1291.50 194.41 218.43]
FZKHtreBM=[15.97 31.36 43.06 97.42 104.04 25.59 25.11 31.96 129.04]

Pressure impulses IP (kPa.s) and their durations tre+tf1 & tre+f2 (ms)

FZK low aeration data:

LIPref1=[0.0322 0.8241 1.6993 0.1176 1.9603 1.4936 1.1059 2.2326 1.4825 1.4825
1.1864 0.4666 2.4246 1.8219 1.0164 1.1185 1.7736 0.0920 0.1476 0.6955
0.8413 0.2775 1.2352 0.2616 0.3442 0.4418 1.6783 0.4521 1.0710 1.2527
0.8404 1.6423]
Ltref1=[1.57 7.67 28.99 0.93 31.66 41.98 21.73 50.90 18.19 18.19 23.58
24.35 63.41 69.38 20.35 75.96 84.08 10.14 11.00 8.51 41.91 12.52
15.99 8.71 20.79 31.50 54.55 20.84 29.00 40.33 56.69 81.33]

LIPref2=[0.0683 1.5077 2.2343 1.1549 3.0648 1.9261 1.5013 6.3818 2.2774 8.2086
1.5760 1.0857 2.9192 6.2869 1.9283 1.4595 4.7019 0.3551 1.0360 1.0412
1.6999 0.3678 1.7268 0.8098 1.5119 0.6895 2.1664 0.7764 2.5919 1.6434
1.3216 1.9466]
Ltref2=[5.37 48.87 62.19 32.93 90.36 80.78 61.43 355.30 67.59 294.55
50.88 95.75 155.91 416.08 101.45 143.56 348.28 80.64 120.40 33.81
120.61 20.82 42.49 61.51 309.99 62.80 111.25 61.94 201.60 101.13
109.29 101.43]

High aeration:

HIPref1=[1.4156 1.4455 1.5034 4.4816 3.4256 0.9918 3.2059 3.1872 1.6602 2.4125
2.3427 1.6178 1.5977 3.5817 1.8864 1.6028 3.0763 0.9286 1.2062 0.8072
0.7508 1.4333 2.3592 1.0246 0.2061 2.2455]
Htref1=[60.94 55.40 58.03 127.74 119.52 18.87 130.56 120.31 78.54 55.95
63.81 70.94 35.18 162.34 97.08 50.19 67.27 48.64 29.58 61.02 43.46
25.85 93.90 39.83 18.52 81.92]

HIPref2=[2.5456 6.8613 4.2608 7.5289 5.1068 2.8914 5.0309 8.9675 2.0718 3.3861
3.3936 2.4536 2.8870 4.6207 3.3057 3.1002 4.8969 2.0809 2.0284 1.8164
0.9907 2.2035 3.4318 1.9468 0.8375 3.4968]

Htref2=[154.24 362.70 313.23 321.54 278.62 142.47 320.56 555.11 170.64 202.65
200.21 188.94 151.28 259.54 270.68 170.29 212.17 182.94 117.48 207.72 94.76
134.35 216.10 110.73 144.22 247.92]

Fmax (kN/m) values for low (L) & high (H) aeration impacts.

Note: 1 All horizontal force estimates are for the same range of elevations as the field data and are at model scale.

2 Only data from the FZK array is used to obtain the force estimates as this has a higher spatial resolution than the PAU array.

LFmax=[105.00 69.00 43.09 38.58 157.70 71.51 58.54 38.24 16.07 14.03 29.81 8.19
11.70 17.42 11.92 10.06 12.62 21.58 11.66 12.20]

HFmax=[31.32 53.59 72.96 24.63 17.75 84.53 42.17 20.13]

Force impulses IF (kN.s/m) and their durations tre+tf1 & tre+f2 (ms)

% FZK Low-aeration data:

LIFref1=[1.142 1.816 1.260 0.390 0.950 0.778 1.108 0.369 0.989 1.624 0.064 0.140
0.092 0.279 0.127 0.213 0.528 0.615 0.165 0.277]

LFtref1=[7.7 29.0 42.0 21.7 18.2 23.6 63.4 20.3 76.0 84.1 8.5 41.9
12.5 8.7 21.5 39.4 54.6 39.8 20.8 56.7]

LIFref2=[1.599 3.619 2.162 0.979 2.997 1.380 2.562 1.189 2.139 3.121 0.372
0.696 0.478 0.776 0.456 0.491 0.755 1.384 0.626 1.174]

LFtref2=[66.4 219.9 127.6 118.3 137.8 61.1 252.4 107.1 253.0 423.5 93.9
204.5 107.6 150.5 101.1 90.6 103.1 178.9 130.2 161.4]

High aeration data:

HIFref1=[5.029 3.396 2.827 2.346 0.368 0.501 0.515 0.241 0.434]
HFtref1=[58.0 119.5 35.2 162.3 97.1 43.5 25.8 40.3 81.9]

HIFref2=[8.199 5.575 4.140 3.850 1.433 1.010 1.210 0.912 1.342]
HFtref2=[536.5 289.1 194.1 331.1 233.5 153.1 146.6 94.5 205.7]

Aeration levels

Average (B%) aeration levels at the time of PQHmax
PAUs 1 & 2 are 4.7m, & 6.26m above CD. Pressures (P) are as measured (kPa).

Low-aeration average B% and average pressure at PAU1 & PAU2:

LB1=[9.50 9.54 9.66 12.31 10.05 9.40 9.43 9.50 10.90]
LP1=[16.16 14.32 12.52 11.27 15.27 4.50 4.54 5.72 4.28]

LB2=[7.8 9.99 8.37 9.95 8.95 9.55 7.79 10.80 11.36]
LP2=[12.33 9.86 8.42 7.00 11.13 2.41 2.26 2.51 2.53]

High-aeration average B% and average pressure at PAU1 & PAU2:

HB1=[9.5 9.9 9.6 10.0 9.7 11.1 9.68 9.54 9.74 9.57 9.40 11.2 10.19
10.12 9.8 10.2 10.2]

HP1=[16.88 16.74 17.49 12.78 12.67 14.18 10.49 17.69 14.03 15.55 16.37 12.38 6.13
7.62 5.87 9.86 5.44]

HB2=[9.8 9.4 9.5 11.4 9.17 12.0 9.77 10.47 7.94 7.71 9.58 10.7 9.4
8.4 9.4 10.9 9.9]

HP2=[12.35 11.97 13.18 7.77 8.23 10.16 8.26 10.07 9.16 10.92 11.8 7.9 3.61
4.69 3.77 5.69 3.52]

ERC oscillations in HA impacts

E1 & RC1 values as measured by PAUs & FZKs (kPa):

E1= [7.12 5.20 5.71 19.48 -12.32 -53.26 -6.88 -17.78 -4.39 14.99 -5.07 -2.04 -2.35
3.52 17.88 7.32 1.60 3.60 13.61 -8.12 4.02 -27.13 14.56 3.33]

RC1=[23.97 25.95 28.98 28.45 23.07 41.46 31.99 30.84 27.66 39.91 21.49 18.81 18.58
10.17 23.13 15.72 22.10 18.89 15.14 9.96 6.75 42.33 19.65 14.57]

Period (To ms), Damping Ratio (xi) & Log. Dec. (LD) of p(t)

No discontinuity:

pTo=[77.80 29.98 52.05 31.47 34.65 34.83 37.06 35.13 34.06]

pxi=[0.105 0.120 0.150 0.200 0.083 0.215 0.150 0.140 0.132]

pLD=[0.663 0.759 0.953 1.283 0.521 1.383 0.953 0.888 0.837]

Before a discontinuity:

pTo=[31.87 49.66 50.00 29.47 29.93 23.17 32.79 30.40 47.70]

pxi=[0.300 0.334 0.179 0.190 0.280 0.190 0.186 0.110 0.260]

pLD=[1.976 2.226 1.143 1.216 1.833 1.216 1.189 0.695 1.692]

After a discontinuity:

pTo=[43.00 50.68 39.00 28.28 30.43 21.64 31.43 31.30 42.57]

pxi=[0.064 0.055 0.077 0.074 0.094 0.125 0.086 0.063 0.130]

pLD=[0.403 0.346 0.485 0.466 0.593 0.792 0.542 0.397 0.824]

GWK VERTICAL-WALL DATA

Pmax (kPa) & tre (ms) values listed as low (L) and high (H) aeration in model (m) terms

PAULPmax=[476.07 461.38 261.22 94.39 488.34 284.57 91.43 138.74 270.85 132.41
623.31]

PAULtre=[1.18 0.38 0.41 7.28 0.43 8.88 6.73 20.20 1.17 57.66 0.60]

PAUHPmax=[153.66 83.92 131.17 781.34 237.22 296.99 93.48 192.47 404.16 140.18
252.70 196.56]

PAUHtre=[2.74 80.29 52.65 2.72 18.42 27.17 7.74 5.86 18.41 15.10 20.05 40.11]

FZKLPmax=[58.93 218.54 291.49 79.82 210.96 90.49 206.66 65.99 101.25 183.32]

FZKLtre=[19.36 7.18 10.16 36.61 4.38 11.54 11.12 17.48 17.12 10.41]

FZKHPmax=[229.03 178.38 196.13 166.98 115.04 102.11 344.96 162.99 105.98

173.12 65.56 101.82 127.60 1354.58 102.00 622.54 207.66 109.88 92.65]

FZKHtre=[14.51 10.38 8.30 12.37 5.19 48.66 15.30 45.64 31.42 29.58 8.55 35.95 5.87
0.98 36.33 1.78 15.03 61.20 33.77]

Fall times (ms) from Pmax (kPa) as estimated from model data

tf1* LA PAU & FZK:

PAULPmaxtf1s=[476.07 461.38 261.22 94.39 488.34 284.57 91.43 138.74 270.85 132.41
623.31]

PAULtf1s=[11.0 0.4 0.1 18.5 19.1 21.6 21.4 125.6 8.8 38.8 0.5]

FZKLPmaxtf1s=[291.49 79.82 90.49 206.66 65.99 101.25]

FZKLtf1s=[17.1 29.9 126.4 33.1 128.8 18.0]

tf1* HA PAU & FZK:

PAUHPmaxtf1s=[153.66 781.34 237.22 93.48 192.47 404.16]

PAUHtf1s=[9.8 2.3 119.5 21.0 21.4 24.2]

FZKHPmaxtf1s=[229.03 115.04 344.96 101.82 127.60 1354.58 102.00 92.65]

FZKHtf1s=[21.9 123.4 20.6 61.7 44.4 17.1 59.3 22.7]

tf1 LA PAU & FZK:

PAULPmax=[476.07 461.38 261.22 94.39 488.34 284.57 91.43 138.74
270.85 132.41 623.31]

PAULtf1=[20.9 10.2 1.2 220.6 127.9 119.4 141.6 247.2 18.3 14.0 1.3]

FZKLPmax=[58.93 218.54 291.49 79.82 210.96 90.49 206.66 65.99 101.25 183.32]

FZKLtf1=[105.8 136.5 116.1 100.1 137.9 263.5 123.4 259.8 122.3 19.3]

tf1 HA PAU & FZK:

PAUHPmax=[153.66 83.92 131.17 781.34 237.22 296.99 93.48 192.47 404.16 140.18
252.70 196.56]

PAUHtf1=[106.4 97.7 60.6 34.7 282.9 45.8 128.9 82.2 159.9 80.6 25.2 100.0]

FZKHPmax=[229.03 178.38 196.13 166.98 115.04 102.11 344.96 162.99 105.98 173.12
65.56 101.82 127.60 1354.58 102.00 622.54 207.66 109.88 92.65]
FZKHTf1=[103.4 119.4 122.5 124.5 167.4 64.8 272.4 85.4 71.6 51.7 127.3 175.4 94.6
49.1 178.7 19.3 25.5 80.3 70.2]

tf2 LA PAU & FZK:

PAULtf2=[106.2 130.2 115.4 688.5 347.9 376.4 332.5 442.7 59.3 379.3 32.2]

FZKLtf2=[294.8 478.5 452.2 246.1 575.2 560.5 479.8 556.6 379.0 150.6]

tf2 HA PAU & FZK:

PAUHTf2=[506.0 819.2 673.8 499.4 851.9 630.5 465.4 372.4 361.2 609.7 491.3 577.4]

FZKHTf2=[495.3 459.9 470.0 513.9 797.0 657.7 462.4 807.8 553.2 609.8 598.6 450.1
453.3 404.4 529.1 121.9 333.5 562.5 309.6]

Pmax measured by PAU2 and FZK4 (kPa)

Distance in the GWK between PAU2 & FZK4 = 0.94m. The same event may not be of the same type. Pressures are as measured where L= both LA, H = both HA and B = one LA and the other HA.

PAU2L=[138.74 284.57 79.43 43.25]

FZK4L=[101.25 291.49 73.21 30.62]

PAU2H=[85.61 129.87 124.08 19.62 124.68 171.03 93.48 221.17 237.22 119.21 73.45
142.73]

FZK4H=[115.36 77.24 155.74 51.72 104.79 162.56 53.53 278.82 162.99 102.11 115.04
101.33]

PAU2B=[191.57 136.55 99.07]

FZK4B=[130.63 92.26 108.96]

Variation of Pmax with PQHmsx for both LA & HA events

PAULPmax=[476.07 461.38 261.22 94.39 46.39 488.34 284.57 91.43 138.74 279.85
132.41]

PAULPQHmax=[10.29 9.43 7.71 11.60 19.60 14.22 10.40 15.50 8.95 19.09 10.59]

PAUHPmax=[153.66 83.92 131.17 781.34 237.22 296.99 93.48 192.47 404.16 140.18
252.70 196.56]

PAUHPQHmax=[10.02 23.90 26.60 13.20 14.13 16.80 12.40 4.26 17.95 15.94 11.14
17.35]

FZKLPmax=[58.93 39.92 218.54 291.49 79.82 210.96 90.49 206.66 65.99 101.25 183.32]

FZKLPQHmax=[9.50 20.40 7.76 8.61 6.34 7.27 6.20 8.21 6.00 7.41 6.78]

FZKHPmaxP=[229.03 178.38 196.13 166.98 115.04 112.11 344.96 162.99 105.98 173.12
65.56 101.82 127.60 1354.58 102.00 622.54 207.66 109.88 92.65]

FZKHPQHmax=[11.31 10.10 8.91 9.85 12.70 13.80 11.49 11.87 8.27 11.10 13.55 10.41
5.97 11.79 13.80 7.53 7.07 10.78 8.45]

BM law scaled values of Pmax & tre

PAUHPmax=[593.40 251.51 469.83 8425.70 1161.37 1669.33 291.17 836.12 2778.88
517.83 1284.99 863.79]

PAUHtre=[6.49 236.36 133.48 2.11 34.78 44.46 22.09 12.45 24.14 37.26 36.43 84.27]

FZKHPmax=[1098.29 743.68 860.86 672.53 389.02 328.92 2135.38 648.37 346.47
710.47 181.78 327.61 451.38 20972.40 328.41 5747.43 941.12 364.52
287.64]

FZKHtre=[27.98 22.94 17.47 28.22 13.83 135.04 22.56 105.33 86.12 66.31 26.77
99.85 15.06 0.50 100.87 1.66 30.65 165.70 96.62]

Pressure impulses IP (kPa.s) and their durations tre+tf1 & tre+f2 (ms)

FZK Low-aeration data:

LIPref1=[2.69 1.29 0.13 5.58 3.15 9.15 4.31 4.59 4.20 5.00 3.70 3.41 4.62 4.55
4.86 4.46 4.15 3.19 1.22 6.01 1.59 0.63];

Ltref1=[116.89 62.63 176.16 302.83 182.70 251.91 128.33 143.65 105.89 134.18
131.55 206.09 157.15 319.32 144.04 154.32 313.58 171.37 19.27 186.12 28.27
6.87]

LIPref2=[5.25 3.51 1.48 9.23 4.63 12.72 11.33 6.64 7.01 6.08 8.32 5.73 4.41 7.55
5.93 5.91 7.00 5.59 4.55 1.94 8.41 2.75 1.99]

Ltref2=[107.38 130.58 115.81 695.78 314.16 518.06 644.84 348.33 485.68 385.28
339.23 462.36 282.71 579.58 572.04 462.90 490.92 574.08 396.12 60.47
436.96 161.01 32.80]

High-aeration data:

HIPref1=[3.65 5.67 4.97 4.09 4.74 6.98 6.39 7.26 5.18 4.71 11.10 6.71 7.98 3.04
7.02 4.14 5.39 5.03 4.06 2.21 4.02 8.32 5.46 4.17 4.85 3.74 8.69 2.90 2.83
5.86 2.68]

Htref1=[150.84 142.11 148.61 146.39 144.85 170.81 184.27 111.75 100.77 39.16
304.76 95.43 154.59 362.29 171.64 163.71 78.28 355.89 203.46 115.30
131.73 178.31 312.79 20.56 205.78 41.75 140.11 23.32 81.20 158.61 74.17]

HIPref2=[6.68 9.29 7.73 6.31 7.52 23.55 14.46 22.43 13.06 9.42 18.05 8.46 15.70
6.05 15.69 7.27 11.13 10.60 5.91 3.65 6.33 11.49 11.55 8.34 8.72 8.40 16.59
4.33 5.22 10.89 4.48]

Htref2=[508.74 509.81 470.28 478.30 526.27 899.49 802.19 726.45 706.36 502.12
870.32 477.70 853.44 584.62 657.67 473.14 639.38 607.17 486.05 378.26
459.17 379.61 624.80 405.38 565.43 511.35 617.51 123.68 348.53 623.70
343.37]

Fmax (kN/m) values for low (L) & high (H) aeration impacts.

Note: 1 All GWK horizontal force estimates are for the same range of elevations as the field data and are at model scale.

2 Only data from the FZK array is used to obtain the GWK force estimates as this has a higher spatial resolution than the PAU array.

LFmax=[59.95 180.31 153.47 67.11 165.42 94.00 113.76 69.42 56.31 62.89]

HFmax=[204.37 167.50 162.44 146.01 88.69 139.36 208.20 142.91 80.29 148.78 43.85
43.38 85.01 504.37 42.49 220.10 96.80 65.32 57.72];

Force impulses IF (kN.s/m) and their durations tre+tf1 & tre+tf2 (ms)

FZK low-aeration data:

LIFref1=[5.110 5.788 7.325 3.632 4.925 6.420 7.937 4.827 6.332 3.269 0.663]
LFtref1=[182.7 251.9 143.6 131.5 206.1 157.2 319.3 154.3 313.6 171.4 28.3]

LIFref2=[7.991 7.582 13.355 6.284 6.192 13.244 11.733 8.403 8.686 4.975 1.624]
LFtref2=[407.1 366.5 545.0 480.6 342.2 635.9 655.6 531.8 574.5 411.1 133.8]

High-aeration data:

HIFref1=[7.979 7.376 6.697 7.313 7.538 6.604 2.872 8.392 5.841 4.564 6.476 2.268
4.380 1.774 2.536 1.261 1.980 4.723 1.683]

HFtref1=[142.1 148.6 146.4 144.9 184.3 100.8 95.4 154.6 362.3 78.3 355.9 203.5
131.7 20.6 205.8 23.3 81.2 158.6 74.2]

HIFref2=[16.577 14.856 12.135 15.050 20.223 17.268 6.035 17.409 8.211 5.698 11.188
3.417 8.176 6.429 4.887 2.557 2.639 9.187 3.942]

HFtref2P3=[706.1 608.3 531.6 656.9 1006.0 720.4 473.8 775.5 650.9 194.6 806.5
453.8 497.3 399.0 609.0 136.8 164.4 617.2 358.4]

Aeration levels

Average (B%) aeration levels at the time of PQHmax

PAUs 1 & 2 are 4.4m, & 6.2m above CD. Pressures (P) are as measured (kPa).

Low-aeration average B% and average pressure at PAU1 & PAU2:

LB1=[8.08 8.22 8.03 13.49 7.62 8.14 8.28 11.57 8.08 8.14 8.81 8.25 8.04
11.93 8.46]

LP1=[25.75 24.62 3.53 19.66 23.83 13.62 17.89 15.28 22.07 20.37 20.94 16.30 19.46
10.76 13.99]

LB2=[7.95 6.73 5.58 6.36 5.85 5.55 6.80 9.78 7.87 5.77 5.80 6.06 5.57
10.13 8.32]

LP2=[16.32 15.59 26.53 11.64 14.99 9.20 10.16 8.56 12.80 13.39 12.55 9.02 12.80
4.26 8.04]

High-aeration average B% and average pressure at PAU1 & PAU2

HB1=[8.27 7.95 7.45 8.28 9.70 8.84 8.63 8.50 15.58 8.67 9.95]
HP1=[25.68 23.92 26.42 12.72 22.94 16.60 20.59 16.61 16.38 10.80 16.96]

HB2=[5.73 10.75 9.35 11.56 9.93 13.60 6.85 8.72 30.53 8.86 6.64]
HP2=[16.37 15.15 16.69 10.51 14.15 9.86 12.37 9.37 9.36 5.14 10.03]

ERC oscillations in HA impacts

E1 & RC1 values as measured by PAUs & FZKs (kPa):

E1= [7.49 -1.02 13.19 -10.09 12.61 7.26 -4.60 -11.03 -15.23 -2.58 -7.80 8.57 9.57
7.73 8.22 -1.83 12.67 -13.89 -6.37 -3.10 -14.41 7.48 -10.34 11.82 5.57-8.13
-1.88 6.00 -5.10 -11.38]

RC1=[10.88 37.39 35.23 27.79 32.71 12.54 24.96 43.52 33.61 30.68 31.16 13.15 11.48
9.30 10.68 28.33 19.16 25.78 16.23 9.86 25.65 18.6 16.33 29.66 45.20 20.71
63.75 21.42 19.02 30.27]

Period (To ms), Damping Ratio (xi) & Log. Dec. (LD) of p(t)

No discontinuity:

pTo=[160.00 130.00 124.23 132.70 109.47 11.95 39.77]
pxi=[0.158 0.148 0.148 0.145 0.125 0.150 0.200]
pLD=[1.005 0.940 0.940 0.921 0.792 0.953 1.283]

Before a discontinuity:

pTo=[186.00 182.00 195.00 235.00 160.00 96.00 100.50 113.00 60.80 49.40 124.40
32.00 43.00];
pxi=[0.315 0.395 0.300 0.310 0.257 0.225 0.250 0.083 0.159 0.210 0.130
0.100 0.250]
pLD=[2.085 2.702 1.976 2.049 1.671 1.451 1.622 0.523 1.012 1.350 0.824
0.631 1.622]

After a discontinuity:

pTo=[120.85 116.45 88.49 151.18 118.50 123.00 129.50 52.03 62.57 145.00]
pxi=[0.110 0.140 0.085 0.153 0.246 0.120 0.161 0.080 0.060 0.110]
pLD=[0.695 0.888 0.536 0.973 1.595 0.759 1.025 0.504 0.378 0.695]