IWT SBO PROJECT 120003 "SEARCH"

Archaeological heritage in the North Sea

Development of an efficient assessment methodology and approach towards a sustainable management policy and legal framework in Belgium.

Archeologisch erfgoed in de Noordzee

Ontwikkeling van een efficiënte evaluatiemethodologie en voorstellen tot een duurzaam beheer in België.

SURVEY REPORT RAVERSIJDE - NOV 2014 & OCT 2016

WP1.3.3

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November 2016

Deltares

Enabling Delta Life

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1. Framework and objectives

1.1. Framework

Two geophysical fieldwork campaigns have been carried out on the beach at Raversijde, near Oostende, Belgium in November 2014 and October 2016. These fieldwork campaigns were part of the IWT-SBO project SeArch ("Archaeological heritage in the North Sea: development of an efficient methodology and approach towards a sustainable management policy and legal framework in Belgium"). The purpose of this project is to assess the archaeological potential of the Quaternary deposits in the Belgian part of the North Sea. To this date no efficient survey methodology exists that is particularly aimed at archaeological assessment studies. Standard geophysical and remote sensing techniques are mainly used on an ad hoc basis (if at all), and often these techniques are not well adapted for archaeological investigations. Moreover they are ineffective in large parts of the nearshore zone due to the presence of biogenic gas in the sediments and saline water, and generally cannot be applied appropriately in intertidal areas.

One of the main goals of the SeArch project is to supply a flexible, generic survey methodology through the development and improvement of marine geophysical and remote sensing techniques for seafloor and sub-seafloor imaging, with major focus on acquisition (sources/receivers), data processing and interpretation of high-quality data. This should allow a cost-efficient and accurate assessment of the archaeological potential of the seafloor and sub-seafloor environment.

1.2. Survey Objectives

The survey campaigns, carried out in the intertidal zone on the beach of Raversijde, had multiple objectives:

- Test seismic methods using shear waves and surface waves, both on land (dry beach during low tide) and under water (during high tide) and their ability to cope with biogenic gas.
- Test marine electrical resistivity tomography (ERT) and assess its ability to obtain useful subsurface information in the presence of biogenic gas.
- Compare marine to land ERT in the intertidal setting.

The rationale for using these techniques in this setting is described in the SeArch report Kruiver et al. (2013).

2. Study area

The survey area is between breakwaters ("strandhoofd") 22 and 23 at Raversijde, west of the city of Oostende, Belgium (Figure 1). This area has been selected because of the presence of biogenic gas (Claerhout, 2014, Figure 2).

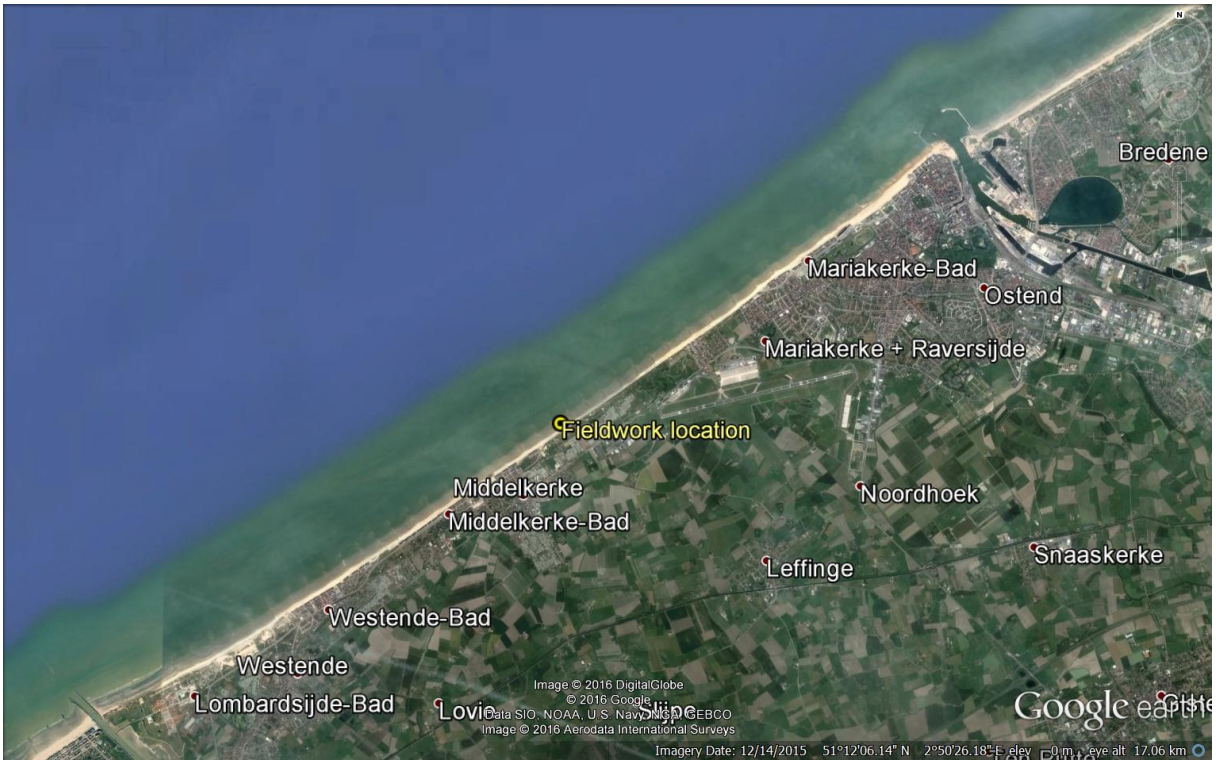

Figure 1. Location of survey area west of city of Oostende and east of Middelkerke, Belgium. Background image from Google Earth.

Figure 2. Strong reflectors (blue), the presence of peat (red), suspected presence of peat (orange) and the presence of gas (green). The red rectangle represents the area between breakwaters 22 and 23. Figure from Claerhout, 2014.

3. List of participants

The survey was carried out in two parts: the first in November 2014 and the second in October 2016. The participants are included in Table 1.

Table 1. Participants in the field campaigns at Raversijde

			2014		2016				
Name	**Organisation**	**Function**	13/11	14/11	10/10	11/10	12/10	13/10	14/10
Tine Missiaen	RCMG	SeArch project manager	x	x					
Oscar Zurita Hurtado	RCMG	Geophysicist	x	x					
Sven van Haelst	AOE	Marine archaeologist	x	x					
Pauline Kruiver	Deltares	Geophysicist			x	x	x	x	x
Mike van der Werf	Deltares	Engineer	x	x	x	x	x	x	x
Martien Goldschmeding	Deltares	Engineer	x	x					
Marco de Kleine	Deltares	Geologist			x	x	x	x	x
Marios Karaoulis	Deltares	Geophysicist				x	x	x	
Arend Aalbers	Hired by Deltares	Engineer			x	x	x	x	x
Alex Kirichek	Hired by Deltares	Geophysicist			x	x	x	x	
Wim Versteeg	VLIZ	Geophysicist						x	x

4. Operations and weather conditions

The fieldwork has been carried out in two phases. The first phase was in November 2014. During the first campaign, the measurements were performed on the beach during and around low tide. In effect, these were land measurements. The second phase (October 2016) was focussed on marine measurements, during high tide while the beach was covered with water. A work permit (no. IO 2003/2016) was obtained from the Municipality and police of Middelkerke to put equipment on the cycle path on the dike. Additionally, the "Afdeling Kust" of the "Agentschap Maritieme Dienstverlening en Kust" was notified of our planned activities. Obtaining the work permit took longer than anticipated. Activities on the beach are not allowed during the tourist season from 15 June till 15 September. As a result, the second survey could not be performed sooner than in October 2016. Although the weather was very nice during the October 2016 survey, the wind was nonetheless too strong and the waves too high for operating a boat. The back-up plan was to use the Impactor source from the beach while the marine streamer was (partially) covered by water during high and receding tide. In this way, both land and marine measurements were performed.

During the second survey, the marine streamer was to be placed on the beach during low tide and then secured by sand bags. This would ensure that the floating streamer would stay on the seabed during high tide. This approach was new and not yet tested. Marine streamers are expensive equipment. Therefore, we first performed a test of this setup with a marine ERT cable. We placed and secured the marine ERT cable on Tuesday. A sandbag was placed every meter. On Wednesday morning, after two high tides, the cable was still in its original position. In this dynamic environment, however, part of the sandbags was partially covered by sand

Figure 3 Left: The marine ERT cable on the beach secured with sandbags during low tide on Tuesday. Right: situation on Wednesday after two high tides. The sandbags and cable are partially covered. Viewpoint in the direction of the sea.

Figure 4 Left: The marine streamers on the beach secured with sandbags during low tide on Wednesday. The location of the marine ERT cable to the left of the streamer is visible by the tracks in the sand. Right: situation on Thursday after two high tides. The streamers are partially covered and the sandbags partially covered or moved. Viewpoint in the direction of the sea.

(Figure 3). The test with the cable and sandbags was successful. The ERT cable was used for marine ERT measurements during the high tide during the day. After the ERT measurements, the marine streamer was placed next to the marine ERT cable and the sandbags were transferred from the marine ERT cable to the marine streamer. Since the marine streamer is floating, extra sandbags were placed to secure it. After two tides, the marine streamer was still in place, but some sandbags were completely covered and some others were moved by the water (Figure 4).

The operations and conditions of both field campaigns are summarised in table 2. The positions of the survey lines are shown in Figure 5. The logs of the measurements are included in Appendix A. Photos of the surveys are included in Appendix B.

Table 2. Operations and conditions

Date	Operations	Conditions
Thursday 13/11/2014	S-wave survey on beach during low tide	Low tide at 11:41 High tide at 17:30
Friday 14/11/2014	MASW on beach during low tide. Source is hammer	High tide at 5:57 Low tide at 12:44 High tide at 18:31
Monday 10/10/2016	1) Departure with all equipment from Utrecht. 2) Arrival at Raversijde. 3) Unload all equipment on cycle path on dike. 4) Check tide conditions.	Fair weather. Low tide at 15:07*
Tuesday 11/10/2016	1) Fill sand bags. 2) Place ERT cable on beach during low tide and secure with sand bags 3) MASW on beach during receding tide. Source is impactor. Shot position interval 2 m. 4 shots per position. Receiver is land streamer which is moved with every shot.	Bright weather. High tide at 9:36 Low tide at 16:18
Wednesday 12/10/2016	1) Land ERT parallel to dike. Protocol gradient array long and short, roll along. Total length = 280 m 2) Marine ERT perpendicular to dike while cable is under water. Protocols dipole-dipole, Wenner and Wenner-Schlumberger 3) Remove ERT cable and place marine streamers at low tide. Secure with sand bags	Cloudy and strong winds. Strong waves at high tide High tide at 10:45 Low tide at 17:20
Thursday 13/10/2016	1) Prepare marine seismic acquisition. 2) Test airgun (OK) 3) Prepare back-up source (impactor) 4) Simon Stevin arrives at high tide, decision that waves are too high for small boat to sail. 5) Performance of back-up plan: source is impactor in beach, receiver is marine streamer which is fixed in position. Shot position interval is 5 m (except for 1st shot, 2 m). Generally 8 shots per position. 6) Demobilise	Few clouds and strong winds. Strong waves at high tide High tide at 11:40 Low tide at 18:17
Friday 14/10/2016	Load equipment on trucks and return to Utrecht.	

*All times represented are in local time (GMT + 2h).

Figure 5 Location of survey lines between breakwaters 22 and 23. Background image from Google Earth.

5. Data acquisition

5.1. Equipment

The equipment is summarised in Table 3. Sketches of the setup of the Scholte wave experiment and the land ERT is included in Appendix A.

Table 3 Characteristics of the equipment used during the survey.

Type of measurement	Measurement unit	Source	Receivers
ERT (land)	ABEM SAS-4000		Electrode cables with spacing of 2 m
ERT (marine)	DAS MPT-1		Marine electrode cable using 25 electrodes with electrode spacing of 2.5 m except for first and last electrode (7.5 m)
MASW (Rayleigh waves)	Geodes	Hammer (Nov 2014) Impactor (Oct 2016)	Mobile land streamer with 1-component 10 Hz vertical geophones. Geophone spacing 1 m. 48 channels. .Offset between source and first receiver 5 m (Hammer, 2014) and 7.3 m (Impactor, 2016).
MASW (Scholte waves)	Geodes	Planned: airgun Executed: Impactor	3 fixed marine streamers with channel spacing of 3.125 m and 24 channels each. Configuration such that first two streamers are parallel and with offset to obtain channel spacing of 1.56 m.
S-wave reflection	Geodes	Elvis vibrator with sweep of 20-320 Hz	Land streamer with 1-component 10 Hz horizontal geophones. Geophone spacing 1 m. 48 channels.

5.2. Recorded data

The recorded data are summarised in Table 4.

Table 4 Recorded data

Type of measurement	Data files
ERT – land	Files libelg01.s4k and lrbelg01.s4k
ERT - marine	DD_4520161012_1336.Data, DD_4520161012_1340.Data, DD_4520161012_1348.Data, DD_4520161012_1406.Data, DD_4520161012_1418.Data, DD_4520161012_1538.Data, WCL_4520161012_1302.Data, WCL_4520161012_1354.Data, WCL_4520161012_1541.Data, WN_4520161012_1331.Data, WN_4520161012_1351.Data, WN_4520161012_1549.Data
MASW (Rayleigh waves)	1.dat to 76.dat (Nov 2014) 1.dat to 187.dat (Oct 2016)
MASW (Scholte waves)	1001.dat to 1328.dat
S-wave reflection	1.sgd to 66.sgd

Additionally, waypoints of streamer, shot and electrode positions were recorded in WGS84 coordinates using a held-held GPS. The coordinates are given in Appendix A.

6. References

Clearhout, C (2014) Marien seismische studie van een getijdengebied (Raversijde-Oostende) met het oog op geo-archeologische kartering. MSc thesis Universiteit Gent

Kruiver, P.P., O. Zurita Hurtado, G. Diaferia, T. Missiaen (2013), Non-conventional survey techniques for marine archaeological investigations WP 1.1.3. SeArch report June 2013.

Appendix A – Logs of measurements

GPS
Thursday-Friday 13-14/11/2014

GPS waypoint	Latitude (WGS84)	Longitude (WGS84)	Easting (UTM)	Northing (UTM)	Zone
332	51.1960380 N	2.8320470 E	488264.54	5671638.83	31U
333	51.1960160 N	2.8320100 E	488261.95	5671636.39	31U
334	51.1960160 N	2.8320100 E	488261.95	5671636.39	31U
335	51.1960150 N	2.8320100 E	488261.95	5671636.27	31U
336	51.1960100 N	2.8320080 E	488261.81	5671635.72	31U
337	51.1950850 N	2.8293830 E	488078.15	5671533.27	31U
338	51.1950680 N	2.8293960 E	488079.06	5671531.38	31U
339	51.1950580 N	2.8293990 E	488079.26	5671530.27	31U
340	51.1949020 N	2.8295150 E	488087.33	5671512.9	31U
341	51.1949470 N	2.8295900 E	488092.58	5671517.89	31U
342	51.1949480 N	2.8295900 E	488092.58	5671518.01	31U
343	51.1949560 N	2.8295650 E	488090.84	5671518.9	31U
344	51.1949470 N	2.8295730 E	488091.39	5671517.9	31U
345	51.1950230 N	2.8297870 E	488106.37	5671526.31	31U
346	51.1951330 N	2.8300270 E	488123.16	5671538.51	31U
347	51.1952050 N	2.8302570 E	488139.25	5671546.48	31U
348	51.1953690 N	2.8305410 E	488159.14	5671564.67	31U
349	51.1954280 N	2.8307480 E	488173.62	5671571.2	31U
350	51.1955190 N	2.8310080 E	488191.81	5671581.28	31U
351	51.1955920 N	2.8313180 E	488213.49	5671589.34	31U
352	51.1957390 N	2.8315890 E	488232.46	5671605.65	31U
353	51.1958060 N	2.8318020 E	488247.36	5671613.07	31U
354	51.1959650 N	2.8319480 E	488257.6	5671630.72	31U
355	51.1967510 N	2.8303610 E	488146.92	5671718.39	31U
356	51.1966520 N	2.8305380 E	488159.26	5671707.35	31U
357	51.1964860 N	2.8307580 E	488174.59	5671688.85	31U
358	51.1963310 N	2.8309150 E	488185.52	5671671.59	31U
359	51.1962210 N	2.8310750 E	488196.67	5671659.33	31U
360	51.1960540 N	2.8312850 E	488211.3	5671640.73	31U
361	51.1958830 N	2.8314700 E	488224.18	5671621.68	31U
362	51.1957600 N	2.8316060 E	488233.66	5671607.98	31U
363	51.1971220 N	2.8302470 E	488139.05	5671759.66	31U

S-wave reflection

Thursday 13/11/2014

Record number	Shot position	Relative position (m)	GPS waypoint	Latitude (WGS84)	Longitude (WGS84)	Easting (UTM)	Northing (UTM)	Zone
4	1	-12	363	51.1971220 N	2.8302470 E	488139.05	5671759.66	31U
5	2	-10						
6	3	-8						
7	4	-6						
8	5	-4						
9	6	-2						
10	7	0						
11	7	-12						
12	8	-10						
13	9	-8						
14	10	-6						
15	11	-4						
16	12	-2						
17	13	0						
18	13	-12						
19	14	-10						
20	15	-8						
21	16	-6						
22	17	-4						
23	18	-2						
24	19	0						
25	19	-12						
26	20	-10						
27	21	-8						
28	22	-6						
29	23	-4						
30	24	-2						
31	25	0						
32	25	-12						
33	26	-10						
34	27	-8						
35	28	-6						
36	29	-4						
37	30	-2						
38	31	0						
39	31	-12						
40	32	-10						
41	33	-8						
42	34	-6						
43	35	-4						
44	36	-2						
45	37	0						
46	37	-12						
47	38	-10						
48	39	-8						
49	40	-6						
50	41	-4						
51	42	-2						
52	43	0						

53	43	-12						
54	44	-10						
55	45	-8						
56	46	-6						
57	47	-4						
58	48	-2						
59	49	0						
60	49	-12						
61	50	-10						
62	51	-8						
63	52	-6						
64	53	-4						
65	54	-2						
66	55	0	334	51.1960160 N	2.8320100 E	488261.95	5671636.39	31U

MASW Rayleigh
Friday 14/11/2014

Record numbers	Shot position	GPS waypoint	Latitude (WGS84)	Longitude (WGS84)	Easting (UTM)	Northing (UTM)	Zone
Line parallel to dike. Direction is from west to east							
1-4	1	344	51.1949470 N	2.8295730 E	488091.39	5671517.9	31U
5-8	2	345	51.1950230 N	2.8297870 E	488106.37	5671526.31	31U
9-12	3	346	51.1951330 N	2.8300270 E	488123.16	5671538.51	31U
13-16	4	347	51.1952050 N	2.8302570 E	488139.25	5671546.48	31U
17-20	5	348	51.1953690 N	2.8305410 E	488159.14	5671564.67	31U
21-24	6	349	51.1954280 N	2.8307480 E	488173.62	5671571.2	31U
25-28	7	350	51.1955190 N	2.8310080 E	488191.81	5671581.28	31U
29-32	8	351	51.1955920 N	2.8313180 E	488213.49	5671589.34	31U
33-36	9	352	51.1957390 N	2.8315890 E	488232.46	5671605.65	31U
37-40	10	353	51.1958060 N	2.8318020 E	488247.36	5671613.07	31U
38-44	11	354	51.1959650 N	2.8319480 E	488257.6	5671630.72	31U
Line perpendicular to dike. Direction is from dike to sea							
45-48	12	355	51.1967510 N	2.8303610 E	488146.92	5671718.39	31U
49-52	13	356	51.1966520 N	2.8305380 E	488159.26	5671707.35	31U
53-56	14	357	51.1964860 N	2.8307580 E	488174.59	5671688.85	31U
57-60	15	358	51.1963310 N	2.8309150 E	488185.52	5671671.59	31U
61-64	16	359	51.1962210 N	2.8310750 E	488196.67	5671659.33	31U
65-68	17	360	51.1960540 N	2.8312850 E	488211.3	5671640.73	31U
69-72	18	361	51.1958830 N	2.8314700 E	488224.18	5671621.68	31U
73-76	19	362	51.1957600 N	2.8316060 E	488233.66	5671607.98	31U

GPS
Tuesday-Thursday 11-13/10/2016

GPS way-point	Latitude (WGS84)	Longitude (WGS84)	Easting (UTM)	Northing (UTM)	Zone	Interval (m)	Remark
1	51.1960530 N	2.8315000 E	488226.32	5671640.58	31U		MASW shotpoint 1
2	51.1960660 N	2.8314880 E	488225.49	5671642.03	31U	1.7	MASW shotpoint 2
3	51.1960800 N	2.8314740 E	488224.51	5671643.59	31U	1.8	MASW shotpoint 3
4	51.1960970 N	2.8314620 E	488223.68	5671645.48	31U	2.1	MASW shotpoint 4
5	51.1961160 N	2.8314460 E	488222.57	5671647.6	31U	2.4	MASW shotpoint 5
6	51.1961320 N	2.8314290 E	488221.38	5671649.38	31U	2.1	MASW shotpoint 6
7	51.1961480 N	2.8314130 E	488220.27	5671651.16	31U	2.1	MASW shotpoint 7
8	51.1961660 N	2.8313960 E	488219.09	5671653.16	31U	2.3	MASW shotpoint 8
9	51.1961820 N	2.8313840 E	488218.25	5671654.95	31U	2.0	MASW shotpoint 9
10	51.1961980 N	2.8313670 E	488217.07	5671656.73	31U	2.1	MASW shotpoint 10
11	51.1962110 N	2.8313480 E	488215.74	5671658.18	31U	2.0	MASW shotpoint 11
12	51.1962240 N	2.8313310 E	488214.56	5671659.63	31U	1.9	MASW shotpoint 12
13	51.1962390 N	2.8313100 E	488213.1	5671661.3	31U	2.2	MASW shotpoint 13
14	51.1962550 N	2.8312930 E	488211.91	5671663.08	31U	2.1	MASW shotpoint 14
15	51.1962700 N	2.8312740 E	488210.59	5671664.75	31U	2.1	MASW shotpoint 15
16	51.1962830 N	2.8312550 E	488209.26	5671666.2	31U	2.0	MASW shotpoint 16
17	51.1963000 N	2.8312350 E	488207.87	5671668.09	31U	2.3	MASW shotpoint 17
18	51.1963120 N	2.8312170 E	488206.62	5671669.43	31U	1.8	MASW shotpoint 18
19	51.1963290 N	2.8312010 E	488205.5	5671671.32	31U	2.2	MASW shotpoint 19
20	51.1963430 N	2.8311840 E	488204.32	5671672.88	31U	2.0	MASW shotpoint 20
21	51.1963590 N	2.8311710 E	488203.41	5671674.66	31U	2.0	MASW shotpoint 21
22	51.1963730 N	2.8311580 E	488202.51	5671676.22	31U	1.8	MASW shotpoint 22
23	51.1963890 N	2.8311480 E	488201.81	5671678	31U	1.9	MASW shotpoint 23
24	51.1964050 N	2.8311410 E	488201.33	5671679.78	31U	1.8	MASW shotpoint 24
25	51.1964210 N	2.8311270 E	488200.36	5671681.57	31U	2.0	MASW shotpoint 25
26	51.1964350 N	2.8311170 E	488199.66	5671683.12	31U	1.7	MASW shotpoint 26
27	51.1964500 N	2.8311030 E	488198.69	5671684.79	31U	1.9	MASW shotpoint 27
28	51.1964670 N	2.8310860 E	488197.5	5671686.69	31U	2.2	MASW shotpoint 28
29	51.1964810 N	2.8310690 E	488196.32	5671688.25	31U	2.0	MASW shotpoint 29
30	51.1964850 N	2.8310510 E	488195.06	5671688.7	31U	1.3	MASW shotpoint 30
31	51.1964920 N	2.8310380 E	488194.15	5671689.48	31U	1.2	MASW shotpoint 31
32	51.1965070 N	2.8310160 E	488192.62	5671691.15	31U	2.3	MASW shotpoint 32
33	51.1965290 N	2.8309960 E	488191.23	5671693.6	31U	2.8	MASW shotpoint 33
34	51.1965500 N	2.8309770 E	488189.91	5671695.94	31U	2.7	MASW shotpoint 34
35	51.1965640 N	2.8309610 E	488188.79	5671697.5	31U	1.9	MASW shotpoint 35
36	51.1965810 N	2.8309440 E	488187.61	5671699.39	31U	2.2	MASW shotpoint 36
37	51.1966010 N	2.8309280 E	488186.5	5671701.62	31U	2.5	MASW shotpoint 37
38	51.1966150 N	2.8309130 E	488185.45	5671703.17	31U	1.9	MASW shotpoint 38
39	51.1966320 N	2.8308920 E	488183.99	5671705.07	31U	2.4	MASW shotpoint 39
40	51.1966430 N	2.8308710 E	488182.52	5671706.29	31U	1.9	MASW shotpoint 40
41	51.1966590 N	2.8308550 E	488181.41	5671708.08	31U	2.1	MASW shotpoint 41
42	51.1966720 N	2.8308400 E	488180.37	5671709.52	31U	1.8	MASW shotpoint 42
43	51.1966850 N	2.8308260 E	488179.39	5671710.97	31U	1.8	MASW shotpoint 43
44	51.1966960 N	2.8308100 E	488178.28	5671712.2	31U	1.7	MASW shotpoint 44
45	51.1967140 N	2.8307910 E	488176.95	5671714.2	31U	2.4	MASW shotpoint 45
46	51.1967290 N	2.8307750 E	488175.84	5671715.87	31U	2.0	MASW shotpoint 46
47	51.1967410 N	2.8307530 E	488174.3	5671717.21	31U	2.0	MASW shotpoint 47
48	51.1963320 N	2.8311780 E	488203.9	5671671.66	31U		
49	51.1961380 N	2.8313000 E	488212.37	5671650.07	31U		start of leadin of marine ERT cable
50	51.1966650 N	2.8306470 E	488166.88	5671708.78	31U	74.3	1st electrode trio of

							marine ERT cable
51	51.1967220 N	2.8305770 E	488162	5671715.13	31U	8.0	2nd electrode trio of marine ERT cable
52	51.1972290 N	2.8299360 E	488117.34	5671771.61	31U	72.0	last sand bag on marine ERT cable
53	51.1960370 N	2.8321540 E	488272.02	5671638.7	31U		land ERT cable 2: 1st electrode
54	51.1960420 N	2.8321430 E	488271.25	5671639.26	31U	1.0	land ERT cable 2: 1st electrode
55	51.1959540 N	2.8319080 E	488254.81	5671629.51	31U	19.1	land ERT cable 2: 10th electrode
56	51.1958400 N	2.8316390 E	488235.98	5671616.87	31U	22.7	land ERT cable 2: last electrode
57	51.1957600 N	2.8314560 E	488223.17	5671608	31U	15.6	land ERT cable 3: 10th electrode
58	51.1956420 N	2.8311710 E	488203.23	5671594.93	31U	23.8	land ERT cable 3: last electrode
59	51.1955640 N	2.8309570 E	488188.26	5671586.29	31U	17.3	land ERT cable 4: 10th electrode
60	51.1954500 N	2.8306980 E	488170.13	5671573.65	31U	22.1	land ERT cable 4: last electrode
61	51.1953670 N	2.8304780 E	488154.74	5671564.46	31U	17.9	land ERT cable 5: 10th electrode
62	51.1952500 N	2.8302200 E	488136.68	5671551.49	31U	22.2	land ERT cable 5: last electrode
63	51.1952400 N	2.8302360 E	488137.8	5671550.37	31U	1.6	land ERT cable 5: last electrode
64	51.1951600 N	2.8300070 E	488121.77	5671541.51	31U	18.3	land ERT cable 6: 10th electrode
65	51.1950510 N	2.8297400 E	488103.09	5671529.44	31U	22.2	land ERT cable 6: last electrode
66	51.1950440 N	2.8297140 E	488101.27	5671528.66	31U	2.0	land ERT cable 6: last electrode
67	51.1950410 N	2.8297080 E	488100.85	5671528.33	31U	0.5	land ERT cable 6: last electrode
68	51.1949380 N	2.8294850 E	488085.24	5671516.91	31U	19.3	land ERT cable 7: 10th electrode
69	51.1949370 N	2.8294870 E	488085.38	5671516.8	31U	0.2	land ERT cable 7: 10th electrode
70	51.1948290 N	2.8292120 E	488066.14	5671504.83	31U	22.7	land ERT cable 7: last electrode
71	51.1962760 N	2.8310830 E	488197.24	5671665.45	31U		Centre of 1st channel of long streamer
72	51.1962710 N	2.8310770 E	488196.82	5671664.89	31U	0.7	Centre of 1st channel of short streamer, 1.56 m offset
73	51.1962850 N	2.8310640 E	488195.92	5671666.45	31U	1.8	Centre of 2nd channel of long streamer
74	51.1962950 N	2.8310490 E	488194.87	5671667.57	31U	1.5	Centre of 2nd channel of short streamer
75	51.1963070 N	2.8310320 E	488193.69	5671668.9	31U	1.8	Centre of 3rd channel of long streamer
76	51.1967970 N	2.8304340 E	488152.03	5671723.49	31U	68.7	Centre of last channel of short streamer
77	51.1967950 N	2.8304350 E	488152.1	5671723.27	31U	0.2	Centre of last channel of short streamer
78	51.1973070 N	2.8297870 E	488106.95	5671780.31	31U	72.7	Centre of last channel of long streamer, at low water mark
79	51.1956010 N	2.8319660 E	488258.77	5671590.24	31U		Scholte shot position 1, wrong coordinates
80	51.1956010 N	2.8319660 E	488258.77	5671590.24	31U	0.0	Scholte shot position 2, wrong coordinates
81	51.1962550 N	2.8311670 E	488203.11	5671663.1	31U	91.7	Scholte shot position 3
82	51.1962860 N	2.8311240 E	488200.11	5671666.55	31U	4.6	Scholte shot position 4
83	51.1963150 N	2.8310770 E	488196.83	5671669.79	31U	4.6	Scholte shot position 5

84	51.1963380 N	2.8310350 E	488193.91	5671672.35	31U	3.9	Scholte shot position 6
85	51.1963730 N	2.8309870 E	488190.56	5671676.25	31U	5.1	Scholte shot position 7
86	51.1964030 N	2.8309410 E	488187.35	5671679.59	31U	4.6	Scholte shot position 8
87	51.1964370 N	2.8308920 E	488183.94	5671683.38	31U	5.1	Scholte shot position 9
88	51.1964660 N	2.8308480 E	488180.87	5671686.61	31U	4.5	Scholte shot position 10
89	51.1964960 N	2.8308030 E	488177.74	5671689.96	31U	4.6	Scholte shot position 11
90	51.1964620 N	2.8307100 E	488171.23	5671686.19	31U	7.5	Scholte shot position 12
91	51.1964330 N	2.8306330 E	488165.84	5671682.98	31U	6.3	Scholte shot position 13
92	51.1964000 N	2.8305640 E	488161.01	5671679.32	31U	6.1	Scholte shot position 14
93	51.1963740 N	2.8304960 E	488156.25	5671676.44	31U	5.6	Scholte shot position 15
94	51.1965360 N	2.8308650 E	488182.08	5671694.4	31U	31.5	Scholte shot position 16
95	51.1965020 N	2.8309060 E	488184.93	5671690.61	31U	4.7	Scholte shot position 17
96	51.1964710 N	2.8309430 E	488187.51	5671687.16	31U	4.3	Scholte shot position 18
97	51.1964400 N	2.8309790 E	488190.02	5671683.7	31U	4.3	Scholte shot position 19
98	51.1964050 N	2.8310100 E	488192.18	5671679.81	31U	4.4	Scholte shot position 20
99	51.1963680 N	2.8310610 E	488195.73	5671675.68	31U	5.4	Scholte shot position 21
100	51.1963410 N	2.8310990 E	488198.38	5671672.67	31U	4.0	Scholte shot position 22
101	51.1963050 N	2.8311460 E	488201.65	5671668.66	31U	5.2	Scholte shot position 23
102	51.1962700 N	2.8311910 E	488204.79	5671664.76	31U	5.0	Scholte shot position 24
103	51.1962340 N	2.8312310 E	488207.57	5671660.75	31U	4.9	Scholte shot position 25
104	51.1962240 N	2.8312470 E	488208.69	5671659.64	31U	1.6	Scholte shot position 26
105	51.1962470 N	2.8311750 E	488203.66	5671662.21	31U	5.6	Scholte shot position 27
106	51.1962160 N	2.8312530 E	488209.11	5671658.75	31U	6.5	Scholte shot position 28
107	51.1963010 N	2.8311190 E	488199.77	5671668.22	31U	13.3	Marine streamer, 1st hydrophone
108	51.1963580 N	2.8311090 E	488199.08	5671674.56	31U	6.4	Walking to the end with a waypoint every now and then
109	51.1963800 N	2.8310770 E	488196.85	5671677.01	31U	3.3	should be between the lines of 81-89 and 106-94
110	51.1964080 N	2.8310400 E	488194.27	5671680.13	31U	4.0	but is offset (but which ones?)
111	51.1964480 N	2.8309850 E	488190.44	5671684.59	31U	5.9	
112	51.1964860 N	2.8309280 E	488186.47	5671688.83	31U	5.8	
113	51.1965070 N	2.8308970 E	488184.31	5671691.17	31U	3.2	
114	51.1965380 N	2.8308630 E	488181.94	5671694.62	31U	4.2	
115	51.1965720 N	2.8308230 E	488179.15	5671698.41	31U	4.7	
116	51.1966020 N	2.8307840 E	488176.44	5671701.75	31U	4.3	
117	51.1966350 N	2.8307420 E	488173.51	5671705.43	31U	4.7	
118	51.1966670 N	2.8307010 E	488170.65	5671708.99	31U	4.6	
119	51.1967040 N	2.8306540 E	488167.38	5671713.11	31U	5.3	
120	51.1967340 N	2.8306140 E	488164.59	5671716.46	31U	4.4	
121	51.1967670 N	2.8305750 E	488161.87	5671720.13	31U	4.6	
122	51.1968080 N	2.8305220 E	488158.18	5671724.7	31U	5.9	
123	51.1968400 N	2.8304760 E	488154.98	5671728.27	31U	4.8	~ End of short streamer (buried under sand)
124	51.1968560 N	2.8304510 E	488153.23	5671730.05	31U	2.5	
125	51.1969080 N	2.8304020 E	488149.82	5671735.84	31U	6.7	
126	51.1969480 N	2.8303560 E	488146.62	5671740.3	31U	5.5	
127	51.1969820 N	2.8303120 E	488143.55	5671744.08	31U	4.9	
128	51.1970140 N	2.8302700 E	488140.63	5671747.65	31U	4.6	
129	51.1970480 N	2.8302270 E	488137.63	5671751.44	31U	4.8	
130	51.1970900 N	2.8301730 E	488133.87	5671756.12	31U	6.0	
131	51.1971230 N	2.8301330 E	488131.08	5671759.79	31U	4.6	
132	51.1971650 N	2.8300730 E	488126.9	5671764.47	31U	6.3	
133	51.1971810 N	2.8300490 E	488125.23	5671766.26	31U	2.4	Low water mark at 16:39

MASW Rayleigh
Tuesday 11/10/2016

Rec. no	Shot pos.	Remark	GPS way-point	Latitude (WGS84)	Longitude (WGS84)	Easting (UTM)	Northing (UTM)	Zone
1-4	1	Direction is from dike to sea	1	51.1960530 N	2.8315000 E	488226.32	5671640.58	31U
5-8	2		2	51.1960660 N	2.8314880 E	488225.49	5671642.03	31U
9-12	3		3	51.1960800 N	2.8314740 E	488224.51	5671643.59	31U
13-16	4		4	51.1960970 N	2.8314620 E	488223.68	5671645.48	31U
17-20	5		5	51.1961160 N	2.8314460 E	488222.57	5671647.6	31U
21-24	6	Adjust string of impactor	6	51.1961320 N	2.8314290 E	488221.38	5671649.38	31U
25-28	7	record 28: tram	7	51.1961480 N	2.8314130 E	488220.27	5671651.16	31U
29-32	8		8	51.1961660 N	2.8313960 E	488219.09	5671653.16	31U
33-36	9		9	51.1961820 N	2.8313840 E	488218.25	5671654.95	31U
37-40	10		10	51.1961980 N	2.8313670 E	488217.07	5671656.73	31U
38-44	11		11	51.1962110 N	2.8313480 E	488215.74	5671658.18	31U
45-48	12	record 46: tram	12	51.1962240 N	2.8313310 E	488214.56	5671659.63	31U
49-52	13		13	51.1962390 N	2.8313100 E	488213.1	5671661.3	31U
53-56	14		14	51.1962550 N	2.8312930 E	488211.91	5671663.08	31U
57-60	15		15	51.1962700 N	2.8312740 E	488210.59	5671664.75	31U
61-64	16		16	51.1962830 N	2.8312550 E	488209.26	5671666.2	31U
65-68	17	record 67: tram	17	51.1963000 N	2.8312350 E	488207.87	5671668.09	31U
69-72	18		18	51.1963120 N	2.8312170 E	488206.62	5671669.43	31U
73-76	19		19	51.1963290 N	2.8312010 E	488205.5	5671671.32	31U
77-80	20		20	51.1963430 N	2.8311840 E	488204.32	5671672.88	31U
81-84	21		21	51.1963590 N	2.8311710 E	488203.41	5671674.66	31U
85-88	22	record 85: 2 trams	22	51.1963730 N	2.8311580 E	488202.51	5671676.22	31U
89-92	23		23	51.1963890 N	2.8311480 E	488201.81	5671678	31U
93-96	24		24	51.1964050 N	2.8311410 E	488201.33	5671679.78	31U
97-100	25		25	51.1964210 N	2.8311270 E	488200.36	5671681.57	31U
101-104	26		26	51.1964350 N	2.8311170 E	488199.66	5671683.12	31U
105-108	27		27	51.1964500 N	2.8311030 E	488198.69	5671684.79	31U
109-112	28		28	51.1964670 N	2.8310860 E	488197.5	5671686.69	31U
113-116	29		29	51.1964810 N	2.8310690 E	488196.32	5671688.25	31U
117-120	30		30	51.1964850 N	2.8310510 E	488195.06	5671688.7	31U
121-124	31		31	51.1964920 N	2.8310380 E	488194.15	5671689.48	31U
125-128	32		32	51.1965070 N	2.8310160 E	488192.62	5671691.15	31U
129-132	33		33	51.1965290 N	2.8309960 E	488191.23	5671693.6	31U
133-136	34		34	51.1965500 N	2.8309770 E	488189.91	5671695.94	31U
137-140	35		35	51.1965640 N	2.8309610 E	488188.79	5671697.5	31U
141-144	36		36	51.1965810 N	2.8309440 E	488187.61	5671699.39	31U

145-148	37		37	51.1966010 N	2.8309280 E	488186.5	5671701.62	31U
149-152	38		38	51.1966150 N	2.8309130 E	488185.45	5671703.17	31U
153-156	39		39	51.1966320 N	2.8308920 E	488183.99	5671705.07	31U
157-160	40		40	51.1966430 N	2.8308710 E	488182.52	5671706.29	31U
161-164	41		41	51.1966590 N	2.8308550 E	488181.41	5671708.08	31U
165-168	42		42	51.1966720 N	2.8308400 E	488180.37	5671709.52	31U
169-172	43		43	51.1966850 N	2.8308260 E	488179.39	5671710.97	31U
173-176	44		44	51.1966960 N	2.8308100 E	488178.28	5671712.2	31U
177-180	45		45	51.1967140 N	2.8307910 E	488176.95	5671714.2	31U
181-184	46		46	51.1967290 N	2.8307750 E	488175.84	5671715.87	31U
185-187	47	3 shots only. End of survey because battery of laptop = dead.	47	51.1967410 N	2.8307530 E	488174.3	5671717.21	31U

Land ERT
Wednesday 12/10/2016

Roll out 3 cables
ABEM at 1st position between cables 2 and 3.

Start with gradient protocol long (cable 2+3+4)
Continue with gradient protocol short (cable 2+3)
ERT and IP

Roll along, next position: ABEM at 2nd position between cables 3 and 4
Gradient protocol long & short

Roll out cable 5
ABEM at 3rd position between cables 4 and 5
Gradient protocol long & short
Remove cable 2

etc, to last cable 7 and last ABEM position between cables 6 and 7.
Last cables: only ERT and no IP

Remarks:
Bad connections at cable 2, takeout 7+17 (skip)
This cable was also used as cable 7, again with bad connections at takeout 7+17

Tide is critical for marine ERT, so land ERT is performed only when possible.
Start measuring at ~ 10:30. Finish at ~ 19:15 including demob.

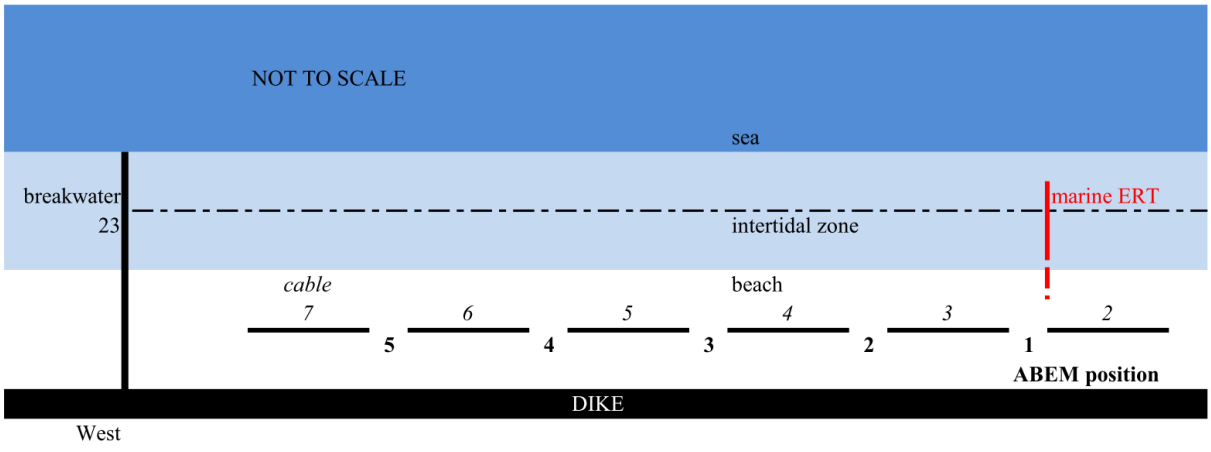

Figure A1 Sketch of ERT setup and position of cables

Marine ERT log
Wednesday 12/10/2016

Steps:

Retrieve connector from begin of cable.

Attach selection of plugs to DAS:

Start measuring at ~ 13:00 with ~ 34 sandbags out of the water

(meaning that the entire cable is still covered by sea water)

13:45 ~ 60 sandbags on beach

14:20 ~ 85 sandbags on beach (so still covered, only just)

total of ~170 sandbags placed over cable

Ready at ~ 16:00
Retrieve ERT cable and move sandbags to marine streamers

Time	Configuration	ERT	IP	Full waveform	File
13:02	Wenner-Schlumberger	x			WCL_4520161012_1302.Data
13:31	Wenner	x			WN_4520161012_1331.Data
13:36-13:48	Dipole-dipole	x	x	x	DD_4520161012_1336.Data, DD_4520161012_1340.Data, DD_4520161012_1348.Data
13:51	Wenner	x			WN_4520161012_1351.Data
13:54	Wenner-Schlumberger	x			WCL_4520161012_1354.Data
14:06-15:38	Dipole-dipole	x	x	x	DD_4520161012_1406.Data, DD_4520161012_1418.Data, DD_4520161012_1538.Data
15:41	Wenner-Schlumberger	x			WCL_4520161012_1541.Data
15:49	Wenner	x			WN_4520161012_1549.Data

MASW Scholte
Thursday 13/10/2016

Record numbers	Shot position	Remark	GPS way-point	Latitude (WGS84)	Longitude (WGS84)	Easting (UTM)	Northing (UTM)	Zone	Distance between points (m)	Remark coordinate
1061-1068	1	Direction is from dike to sea	79	51.1956010 N	2.8319660 E	488258.77	5671590.24	31U		Wrong coordinates
1076 & 1088-1102	2	Shot interval 2 m	80	51.1956010 N	2.8319660 E	488258.77	5671590.24	31U	0.0	Wrong coordinates
1103-1110	3	Shot interval from now on 5 m	81	51.1962550 N	2.8311670 E	488203.11	5671663.1	31U	91.7	
1111-1118	4		82	51.1962860 N	2.8311240 E	488200.11	5671666.55	31U	4.6	
1119-1126	5		83	51.1963150 N	2.8310770 E	488196.83	5671669.79	31U	4.6	
1127-1134	6		84	51.1963380 N	2.8310350 E	488193.91	5671672.35	31U	3.9	
1135-1142	7		85	51.1963730 N	2.8309870 E	488190.56	5671676.25	31U	5.1	
1143-1150	8		86	51.1964030 N	2.8309410 E	488187.35	5671679.59	31U	4.6	
1151-1158	9		87	51.1964370 N	2.8308920 E	488183.94	5671683.38	31U	5.1	
1160-1167	10		88	51.1964660 N	2.8308480 E	488180.87	5671686.61	31U	4.5	
1168-1191	11	24 shots at this position	89	51.1964960 N	2.8308030 E	488177.74	5671689.96	31U	4.6	
1192-1199	12	direction parallel to dike to west	90	51.1964620 N	2.8307100 E	488171.23	5671686.19	31U	7.5	
1200-1207	13		91	51.1964330 N	2.8306330 E	488165.84	5671682.98	31U	6.3	
1208-1215	14		92	51.1964000 N	2.8305640 E	488161.01	5671679.32	31U	6.1	
1216-1223	15		93	51.1963740 N	2.8304960 E	488156.25	5671676.44	31U	5.6	
1225-1232	16	back to position 11 and cross streamer	94	51.1965360 N	2.8308650 E	488182.08	5671694.4	31U	31.5	
1233-1240	17	back towards dike, at same level as position 10	95	51.1965020 N	2.8309060 E	488184.93	5671690.61	31U	4.7	
1241-1248	18	at same level as position 9	96	51.1964710 N	2.8309430 E	488187.51	5671687.16	31U	4.3	
1249-1256	19	etc	97	51.1964400 N	2.8309790 E	488190.02	5671683.7	31U	4.3	
1257-1264	20		98	51.1964050 N	2.8310100 E	488192.18	5671679.81	31U	4.4	
1265-1272	21		99	51.1963680 N	2.8310610 E	488195.73	5671675.68	31U	5.4	
1273-1280	22		100	51.1963410 N	2.8310990 E	488198.38	5671672.67	31U	4.0	
1281-1288	23		101	51.1963050 N	2.8311460 E	488201.65	5671668.66	31U	5.2	
1289-1296	24		102	51.1962700 N	2.8311910 E	488204.79	5671664.76	31U	5.0	

1297-1304	25		103	51.1962340 N	2.8312310 E	488207.57	5671660.75	31U	4.9
1305-1312	26	shot interval 2 m, at same level as position 1	104	51.1962240 N	2.8312470 E	488208.69	5671659.64	31U	1.6
1313-1320	27	very close to streamer, at same level as position 3	105	51.1962470 N	2.8311750 E	488203.66	5671662.21	31U	5.6
1321-1328	28	very close to streamer, at same level as position 4	106	51.1962160 N	2.8312530 E	488209.11	5671658.75	31U	6.5

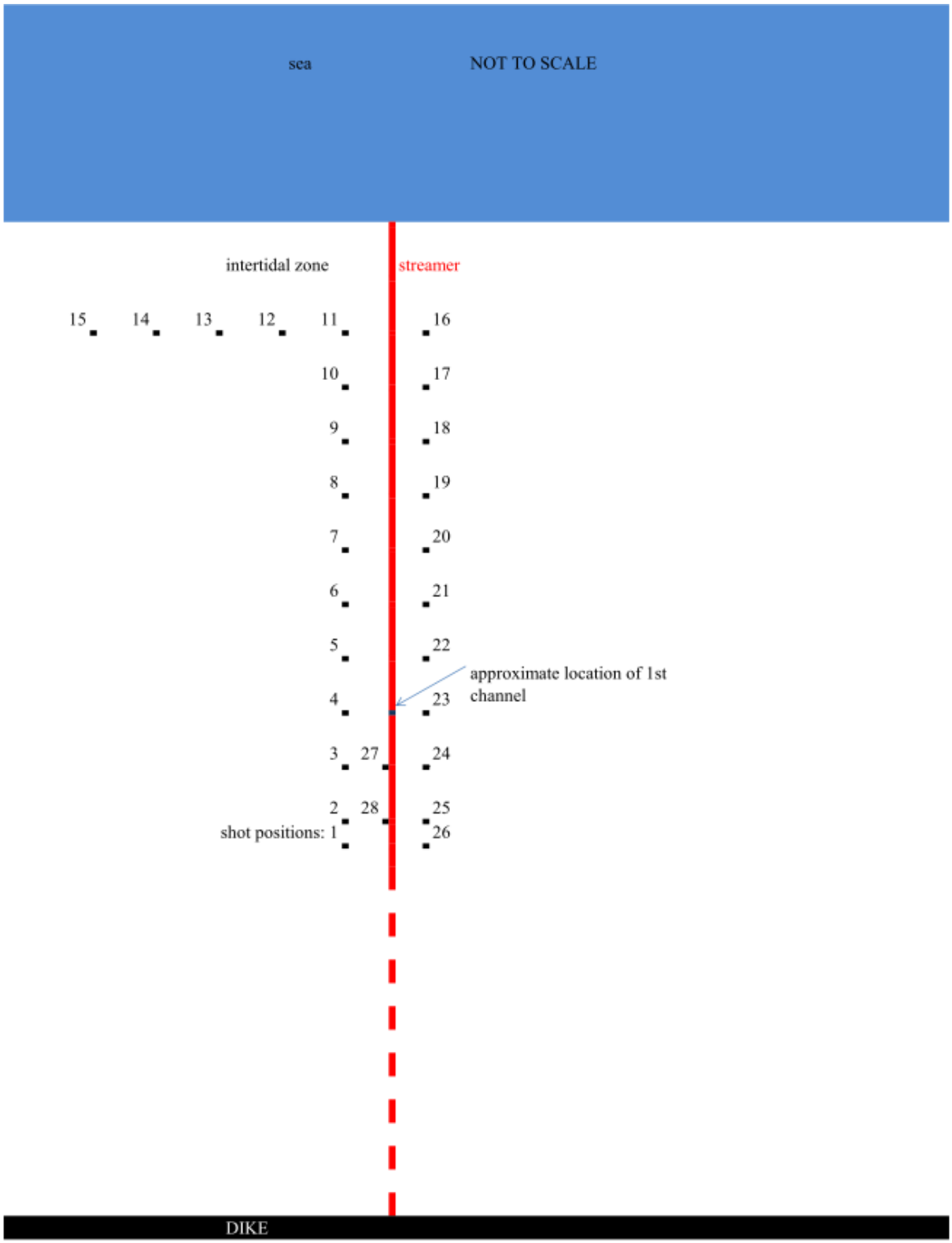

Figure A2 Sketch of Scholte wave experiment setup: positions of shots and marine streamer

Appendix B – Survey photos

Figure B1 S-wave reflection survey (13 November 2014): land streamer with markings for shot locations. Viewpoint in direction of sea.

Figure B2 S-wave reflection survey (13 November 2014): land streamer and source Elvis. Viewpoint in direction of dike.

Figure B3 S-wave reflection survey (13 November 2014): land streamer and markings for shot locations. Viewpoint in direction of dike.

Figure B4 S-wave reflection survey (13 November 2014): setup, viewpoint in direction of sea.

Figure B5 MASW on beach (14 November 2014): hammer blow and land streamer parallel to dike

Figure B6 MASW on beach (14 November 2014): position of streamer parallel to dike. Viewpoint in easterly direction.

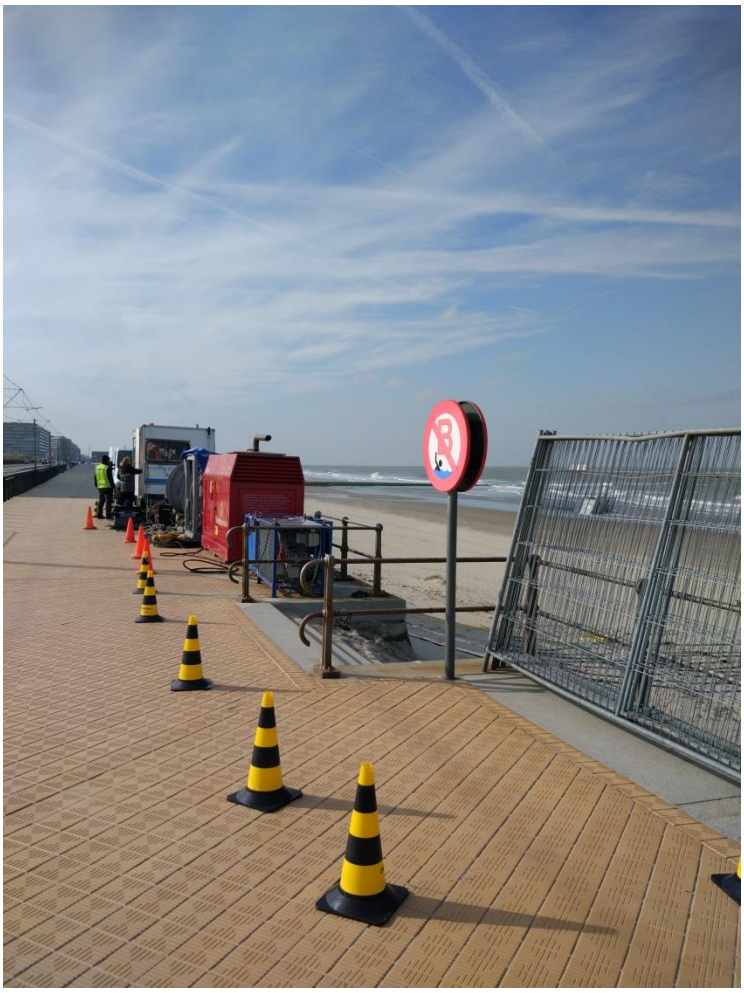

Figure B7 Equipment on the cycle path on the dike.

Figure B8 Filling of sand bags

Figure B9 MASW on the beach with Impactor source (11 October 2016).

Figure B10 Securing the marine ERT cable with sandbags (11 October 2014).

Figure B11 Land ERT on the beach, parallel to the dike (12 October 2016).

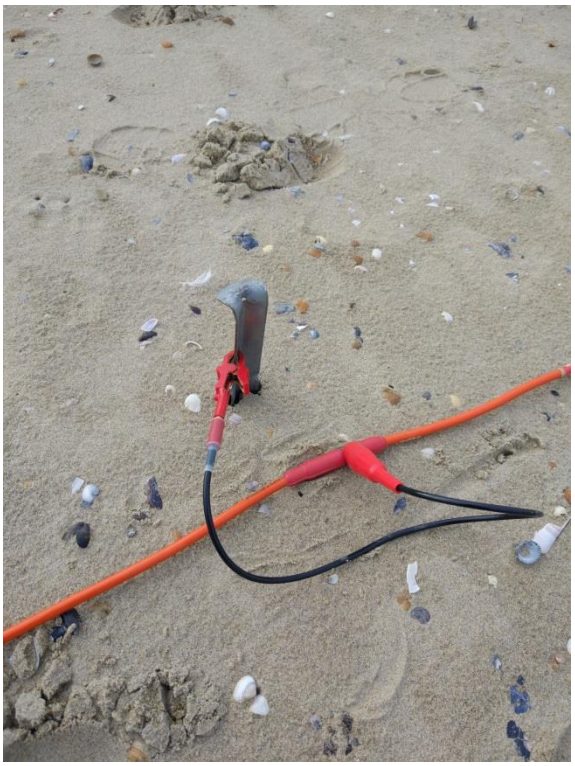

Figure B12 Electrode and cable for land ERT (12 October 2016).

Figure B13 Marine ERT measurements and preparations for the marine streamer (12 October 2016).

Figure B14 Preparing the airgun by attaching floaters (13 October 2016).

Figure B15 Testing the airgun in a water tank. The airtube that supplies the airgun with compressed air is lying to the left of the tank (13 October 2016).

Figure B16 Simon Stevin approaches survey area and returns to Oostende shortly after because the waves are too high. The airtube for the airgun is lying on the beach with floaters attached. The Impactor source (back-up plan) was also ready. 13 October 2016.

Figure B17 Operation of the 3 marine streamers from the shed (13 October 2016).

Firgure B18 Scholte wave experiment with Impactor source and marine streamer covered by water (13 October 2016). Squares are imprints of shots on the beach.