The Great Grid Upgrade

Sea Link

Preliminary Environmental Information Report

Volume: 2

Part 4 Offshore Scheme

Appendix 4.8.B Electromagnetic Deviation Study

Version A

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1. Project Overview

The proposed Sea Link Project comprises a high voltage direct current (HVDC) submarine cable circuit connecting the Sizewell area in Suffolk to the Richborough area in Kent; see Figure 1. For this study the circuit is assumed to have a total capacity of 2 GW and four design options that are explored, set out in Table 1.

There are two options for the northern land fall. The KPs for the main route run from 0 to 127, and for the alternative northern landfall (Route option S6) they are numbered from 8 to 0, in reverse order, so that KP=0 of the alternative option joins the main option between KP= 13 and 14, as in Figure 2.

KPs are between 888 m and 1000 m apart. The maximum depth is 43 m although most of the route is approximately 20 m deep, and for the last few km at the southern end is below 7 m.

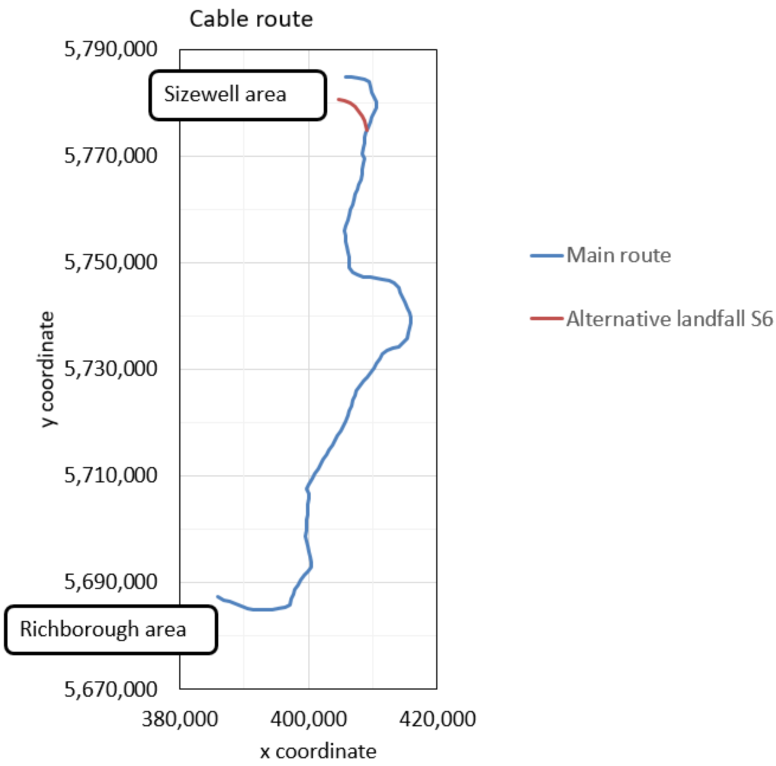


Figure 1 Cable circuit route

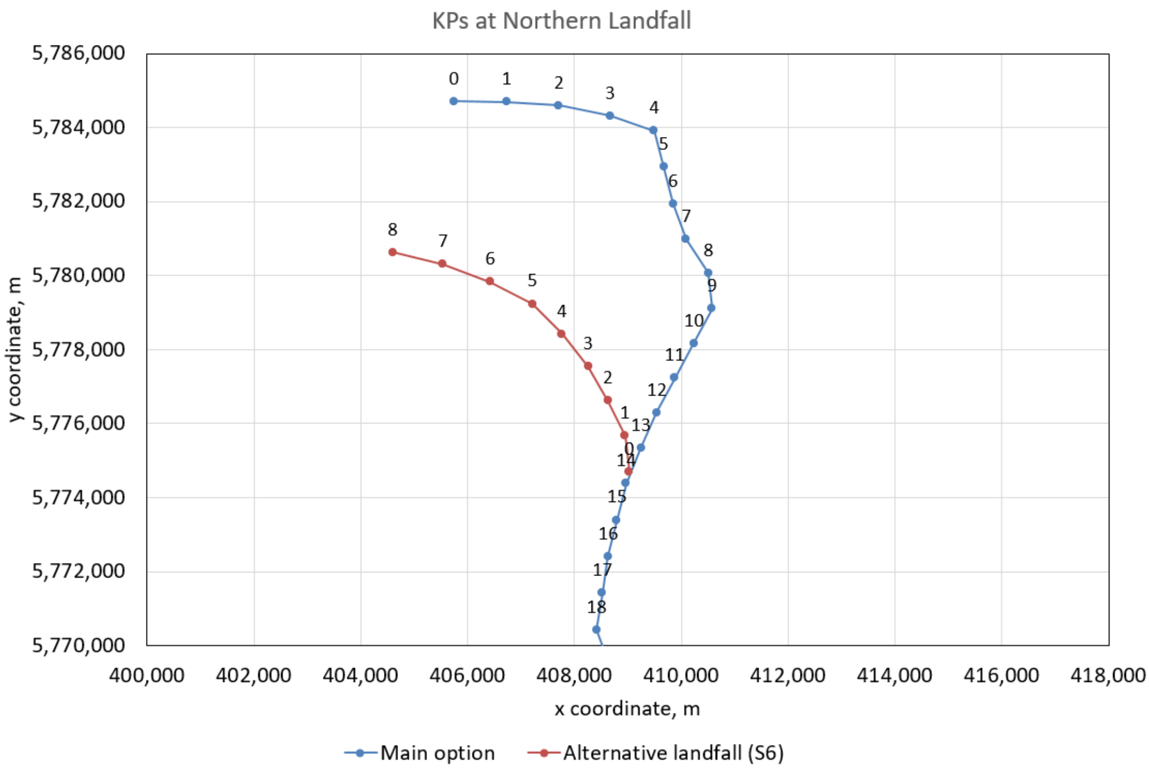


Figure 2 Northern landfall

Option	Cable Configuration	No. of cables	No. of Trenches	Power per cable	Current per cable	Voltage
1	**Bundled**	2	1	1 GW	2000 A	550 kV
2	**Single cables, separated by 200 m**	2	2	1 GW	2000 A	550 kV
3	**Bundled, with a separate metallic return separated by 200 m**	2 with metallic return	2	1 GW	2000 A	550 kV
4	**Two bundled pairs, separated by 200 m**	4	2	500 MW	1000 A	320 kV

Table 1 The four design options assessed in this report

Options 1, 3 and 4 have bundled pairs of cables which are assumed to have a 0.2 m separation.

For the option 3, the main current carrying conductors are bundled and in the same trench with a 0.2 m separation and a metallic return is assumed to carry a maximum unbalanced current of 2% of the load current (i.e., 40 A) under normal operation. Under fault conditions, involving the loss of one of the poles, the metallic return would carry the full pole current and would therefore correspond to option 2 for the duration of the fault.

For option 2, the bipole arrangement with two separated cables, the magnetic field produced by the cable will depend on the current flowing in the cables, the separation of the cables, and the distance from the cables. A bipole system will result in a cancellation of the magnetic fields when the cables are close together. As the cables move apart, as is the case with the separated designs, they will act more like single cables which is the worst-case condition for magnetic fields.

Sections 2, 3 and 4 present assessments of the total magnetic fields, the induced electric fields and the compass deviations, for each of the four options for the proposed route under worst-case load conditions.

2. Magnetic Field Assessment

The maximum magnetic field for each of the four installation options were calculated. The maximum magnetic field was calculated at vertical distances of 0 to 20 meters from the seabed, and horizontal drop off along the seabed. A worst-case (minimum) burial depth of 1 m was used for all calculations.

Figure A1 shows the variation of resultant magnetic field with horizontal distance along the seabed for the four options. For option 3 the bundled pair is shown located at x=50 m and the metallic return at 250 m (rather than 0 m and 200 m), to distinguish their plots from that of option 1, also at 0 m. The calculation results can be found in Appendix A: Table A1 and A2, giving the maximum magnetic field from the cable, and the maximum magnetic field and geomagnetic field combined respectively.

The maximum calculated magnetic fields for all cable designs are compliant with ICNIRP 1994 and 2009 public static magnetic field exposure limits (400 mT) at the seabed surface. The highest magnetic field observed was 406 μT for the separated two-cable design at the seabed, which reduce with vertical and horizontal distance from the cables

For option 2, the separate cable design, the magnetic field resulted in a combined field (cable + geomagnetic field) slightly above the background geomagnetic field to beyond 20 m from the cable. The bundled cable design had significantly lower magnetic fields due to cancellation. These designs typically reduced to a background geomagnetic field within around 8 m from the cable, having only a very localised effect.

For indirect effects such as on implanted medical devices or forces on ferromagnetic objects ICNIRP (2009) suggest restrictions as low as 500 μT. This level of field occurs at 0.8 m from the cable centre from separated cable designs and at 0.45 m from bundled cable designs.

These distances should be maintained in areas where indirect effects of the cables could be observed onshore, such as pacemaker interference.

3. Induced Electric Field Assessment

The HVDC cable will produce a magnetic field which decreases with distance from the cables. The movement of the sea through the magnetic field will result in a small localised electric field being produced. A background electric field will be present in the Sea due to the geo-magnetic field and localised magnetic anomalies. The strength of this field varies continuously due to the strength, speed and directions of the tide.

The convention for calculating induced electric fields for the Basslink, BritNed HVDC and Western Link connections is:

Induced electric field (µV/m) = Velocity (m/s) **x** Magnetic field (µT)

This is a vector cross product which means that the strength of the electric field is proportional to the component of the velocity perpendicular to the magnetic field and is in a direction perpendicular to both. In the absence of information of tidal velocity at the cable's locations, calculations are evaluated for values up to 1.25 m/s, as was used for the Western link cable assessment. The resulting calculated values of induced electric field are between 5 µT and 507 µT.

The geomagnetic field varies between 49.23 µT at Sizewell and 48.98 µT at Richborough[1] and so a value of 49.2 µT is used here for the calculations of induced electric field. This background magnetic field induces an electric field that could range between 4.9 and 61 µV/m in tidal velocities ranging between 0.1 m/s and 1.25 m/s. This does not take account of localised magnetic anomalies, which could result in higher localised electric fields, or of greater tidal velocities.

Table A3 in appendix A gives the calculated induced electric field for each of the four design options at four representative tidal velocities. The separated cable designs produced greater magnetic fields and therefore the greater induced electric fields (up to about 500 µV/m at the seabed for the highest tidal velocity modelled).

Calculations indicate the electric field is highly dependent on the tidal velocity and that the effects around the cables are localised. In the worst-case design, separated two cable operation, the induced electric field falls to values that are of a similar magnitude to that resulting from the geomagnetic field at more than 20 m above the seabed. For the bundled cable designs, the induced electric field falls to values that are similar magnitude to that occurring naturally at about 8 m from the seabed.

[1] From British Geological Survey at www.geomag.bgs.ac.uk/data_service/models_compass/wmm_calc.html

4. Compass Deviations Along the Route

The magnetic field from the cables, if large enough, will combine with the earth's magnetic field causing a compass to indicate north in a different direction to the magnetic north pole.

It is the horizontal component of the geomagnetic field that is used for navigation, and this varies between 19.12 µT in the Sizewell area and 19.59 µT in the Richborough area. A value of 19.6 µT is used for the studies here.

MMO have provided the following guidance:

> *"In relation to Electromagnetic deviation on ships' compasses, the MMO would be willing to accept a three-degree deviation for 95% of the cable route. For the remaining 5% of the cable route no more than five degrees will be attained. The MMO would however expect a deviation survey post the cable being laid; this will confirm conformity with the consent condition. This data must be provided to the UKHO via a hydrographic note (H102), as they may want a precautionary notation on the appropriate Admiralty Charts."*

This statement is problematic in that it does not specify the minimum depth that should apply, and for tidal waters how this relates to low- and high-water levels. There is also scope for considering the width of the affected corridor either side of the cable beneath.

The magnetic fields and compass deviation at the sea's surface were calculated in for all four proposed options along the proposed route. The assessments were performed using cable orientation and depth from Bathymetry data. The orientation of the cables to north, separation and depth, as well as the electric current flowing in the cable, will all impact extent a compass is deviated from the earth's magnetic north.

The maximum compass deviation for each of the design and route options has been calculated along its entire length for the maximum current in the cable. The results are shown in Figure A2 to A5 in Appendix A. The compass deviation is shown as a solid red line for the main route, and as a dotted red line for the alternative landing S6 at the Sizewell area. For smaller currents the compass deviation is smaller. The depth of the seabed is shown as the darker green line.

The depth of the cable, used for the calculation of compass deviation, is deeper than the seabed depth by the 1 m burial depth. Compass deviation calculated at the level of the sea surface. In practice the draft of any vessels will limit the sea depth that applies, and the compass is likely to be situated above the water line, both of which will reduce the compass deviation that will be found in practice.

The compass deviation calculation method has been refined since previous studies, so that it is no longer necessary to perform spot check to assess the validity of the results.

Table 1 gives the percentage of the Sea Link route resulting in compass deviations at the sea surface of less than 3° and 5°. For this the parts of the cable comes ashore, where depth of the seabed becomes negative, are excluded.

The figures and table show:

Option 1: Bundled design (2 cables 0.2 m apart): Very low compass deviation occurs over most of the route. Where the combined sea and burial depth fall below 3 m for the last few km at the Richborough area end of the cable, the compass deviation at maximum current increases rapidly.

Option 2: Separated design (2 cables 200 m apart): The compass deviation at maximum current along most of the route is between approximately 30° and 70° rising even higher near the ends of the route where the cable is shallower. Everywhere is well in excess of the MMO's optimum of 3°, ruling this option out. Reviewing the plots (not shown) with reduced separations of 20 m, 2 m and then 1 m progressively reduced the compass deviations. Even 2 m and 1 m separations, were too much separation, with only 34% of the route below 3° deviation and 68% below 5° (for 2 m separation) and 86% and 91% (for 1 m separation).

Option 3: Bundled design (2 cables 0.2 m apart) with metallic return 200 m away. The compass deviation for the bundled pair will be the same as for option 1. The figure depicts the compass deviation arising from 40 A of the unbalanced net currents flowing in the bundled pair and the metallic return. This is similar to option 2 but with very much smaller current and therefore magnetic field, and resulting in very much smaller compass deviation, remaining below 2° over the whole of the route except the last few km at the Richborough end in shallow waters.

Option 4: Two bundled pairs carrying half the current. This option is similar to option 1 but because each cable carries half as much current, the compass deviation is also approximately halved.

Options 1, 3 and 4 all have values between 97.5% for <3° and <5° variation. The remaining 2.5% of the cable where the deviation exceeds MMO's 5° requirement by a large amount. This occurs at the Richborough end of the cable where it the water is particularly shallow over several km.

Table 1: Percentage of the Sea Link route resulting in compass deviations of less than 3° and 5° variations.

	Proportion of route within compass deviation threshold			
	Bundled	Single cables separated by 200 m	Bundled, with metallic return, separated by 200m	Two bundled pairs separated by 200m
Sea Link Main Route				
Less than 3° deviation	98.4%	0.0%	99.2%	99.2%
Less than 5° deviation	99.2%	0.0%	100.0%	100.0%
Sea Link with S6 entry in Sizewell area				
Less than 3° deviation	97.5%	0.8%	98.3%	98.3%
Less than 5° deviation	98.3%	0.8%	99.2%	99.2%

5. Conclusions

- HVDC cables will produce magnetic fields which inherently comply with ICNIRP occupational and public static exposure limits. Distances of 0.8 m from the cable centre for the separated cable designs and of 0.45 m for bundled cable designs, should be maintained in areas onshore where indirect effects of the cables could be observed, such as pacemaker interference.
- The induced electric fields from all cable designs are localised, with the bundled cables increasing the field above background at up to around 8 m from the seabed, and up to around 20 m for the separated cable design.
- Only the bundled cable designs would meet the less than 3° compass deviation over 95% of the route, criteria from the MMO. However, most of the areas that exceed 3° are in shallow waters and would also exceed the 5° compass deviation requirement by a large margin.
- We might question whether the MMO requirements are reasonable for shallow cable depths, bearing in mind the narrow width of corridor affected and the minimum draft of boats likely to be affected. It is recommended to make a further approach to MMO to seek further clarification.
- The separated cable design (option 2) exceeded 3° compass deviations over the whole route using sea depth and route profile data, possibly resulting in increased consenting risk. Reducing the separation improved matters, but even with a separation of 1 m the deviation fell short of the MMO requirements.

Appendix A: Calculated magnetic fields, induced electric field and compass deviations for Sea Link

Table A1: Calculated maximum magnetic field for each of the four design options for Sea Link. Calculations are provided for increasing vertical distance from the seabed and maximum current load. All calculations were performed for a minimum burial depth of 1 m.

	Maximum magnetic field: cable magnetic field only					
Distance above seabed	**At seabed**	**0.5m**	**1m**	**5m**	**10m**	**20m**
Bundled pair	79.2	35.4	20.0	2.22	0.66	0.18
Separated by 200 m	400.0	266.7	200.0	66.7	36.4	19.0
Bundled pair plus metallic return at 200 m	79.8 / 8.0	36.0 / 5.33	20.5 / 4.0	2.70 / 1.30	1.04 / 0.73	0.44 / 0.34
2 bundled pairs separated by 200 m	39.6	17.70	10.0	1.11	0.33	0.09

Table A2: Calculated maximum total magnetic field from the cables and geomagnetic field combined for each of the four design options for Sea Link. Calculations are provided for increasing vertical distance from the seabed and maximum current load. All calculations were performed for a minimum burial depth of 1 m.

	Maximum magnetic field: cable and geomagnetic field					
Distance above seabed	**Seabed**	**0.5m**	**1m**	**5m**	**10m**	**20m**
Bundled pair	125.9	82.9	68.0	51.3	49.8	49.4
Separated by 200 m	405.7	275.43	211.44	93.13	71.5	60.95
Bundled pair plus metallic return at 200 m	126.2 / 53.1	83.1 / 51.8	68.1 / 51.1	51.4 / 49.9	49.9 / 49.6	49.5 / 49.4
2 bundled pairs separated by 200 m	87.0	65.8	58.5	50.2	49.5	49.3

Figure A1: Calculated magnetic field for each design option demonstrating the horizontal magnetic field drop off along the seabed.

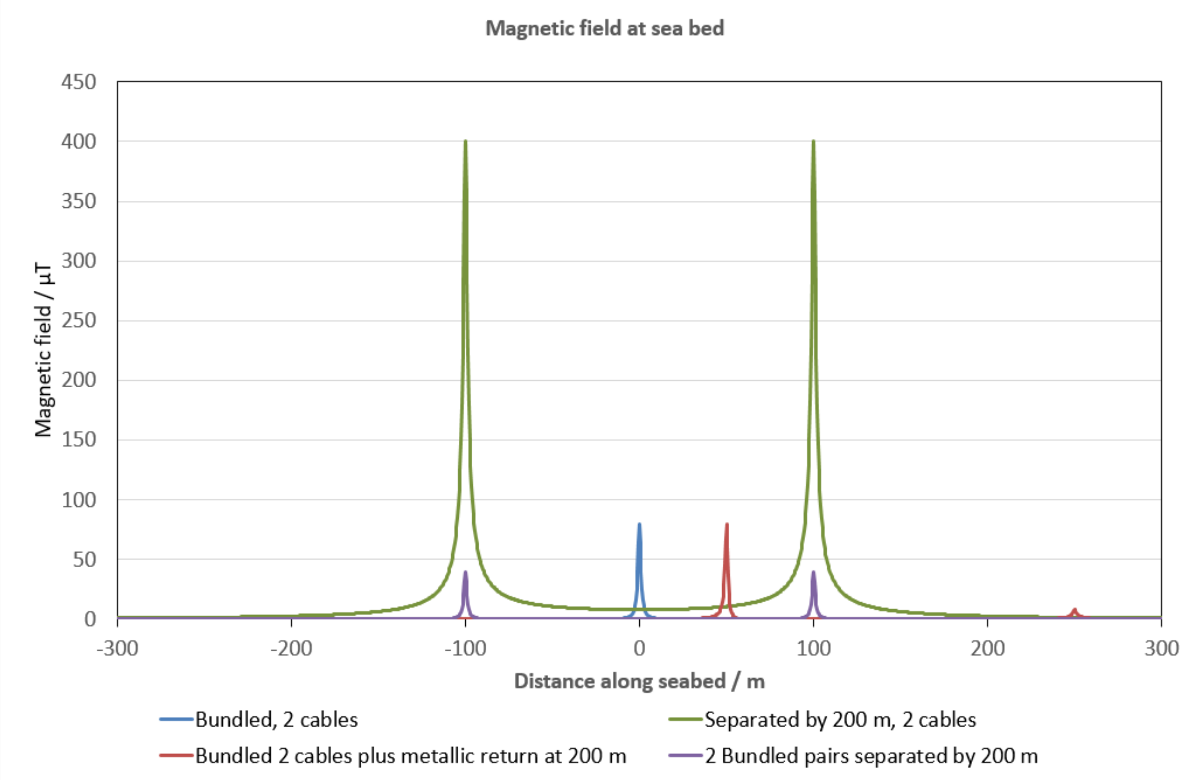


Table A3: Calculated induced electric field for each cable design using the calculated magnetic fields provided in Table A2. The induced electric field was calculated for a range of tidal velocities at increasing vertical distances from the cables.

Induced electric field (µV/m)						
Tidal velocity	**Distance above seabed**	**Field µT**	**0.1 m/s**	**0.3 m/s**	**0.75 m/s**	**1.25 m/s**
Bundled pair	Seabed	125.90	12.59	37.77	94.43	157.38
	0.5 m	82.90	8.29	24.87	62.18	103.63
	1 m	68.00	6.80	20.40	51.00	85.00
	5 m	51.30	5.13	15.39	38.48	64.13
	10 m	49.80	4.98	14.94	37.35	62.25
	20 m	49.40	4.94	14.82	37.05	61.75
Single cables	Seabed	405.70	40.57	121.71	304.28	507.13
separated by 200 m	0.5 m	275.43	27.54	82.63	206.57	344.29
	1 m	211.44	21.14	63.43	158.58	264.30
	5 m	93.13	9.31	27.94	69.85	116.41
	10 m	71.50	7.15	21.45	53.63	89.38
	20 m	60.95	6.10	18.29	45.71	76.19
Bundled pair (with	Seabed	126.20	12.62	37.86	94.65	157.75
metallic return)	0.5 m	83.10	8.31	24.93	62.33	103.88
	1 m	68.10	6.81	20.43	51.08	85.13
	5 m	51.40	5.14	15.42	38.55	64.25
	10 m	49.90	4.99	14.97	37.43	62.38
	20 m	49.50	4.95	14.85	37.13	61.88
Metallic return of	Seabed	53.10	5.31	15.93	39.83	66.38
above, 200 m away	0.5 m	51.80	5.18	15.54	38.85	64.75
	1 m	51.10	5.11	15.33	38.33	63.88
	5 m	49.90	4.99	14.97	37.43	62.38
	10 m	49.60	4.96	14.88	37.20	62.00
	20 m	49.40	4.94	14.82	37.05	61.75
Two bundled pairs	Seabed	87.00	8.70	26.10	65.25	108.75
separated by 200 m	0.5 m	65.80	6.58	19.74	49.35	82.25
	1 m	58.50	5.85	17.55	43.88	73.13
	5 m	50.20	5.02	15.06	37.65	62.75
	10 m	49.50	4.95	14.85	37.13	61.88
	20 m	49.30	4.93	14.79	36.98	61.63

Figure A2: Calculated compass deviations for Sea Link with bundled design. Compass deviations at sea level were calculated along the entire route using the depth to seabed and cable angle to vertical for each station mark.

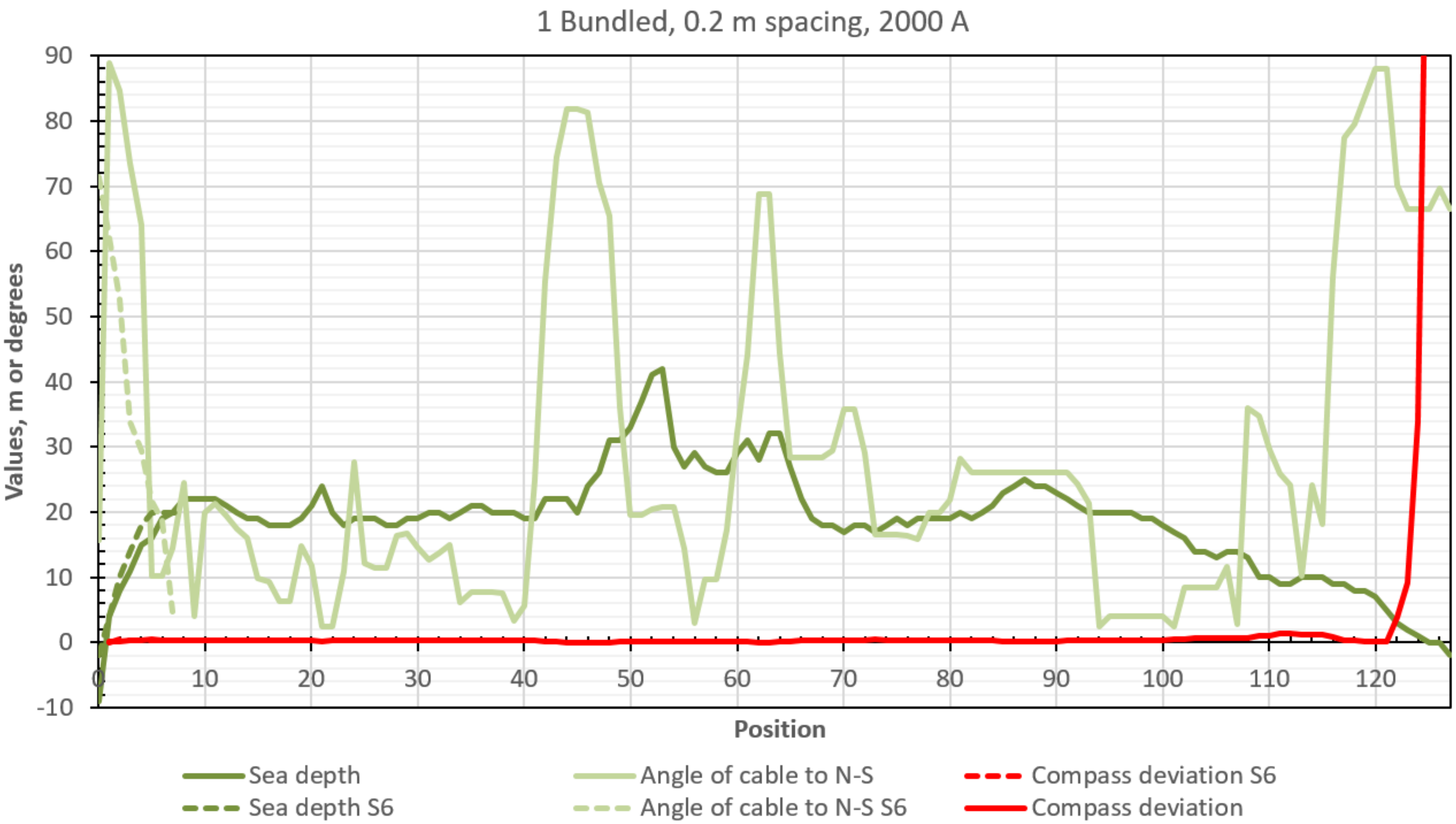


Figure A3: Calculated compass deviations for Sea Link separated cable design. Compass deviations at sea level were calculated along the entire route using the depth to seabed and cable angle to vertical for each station mark.

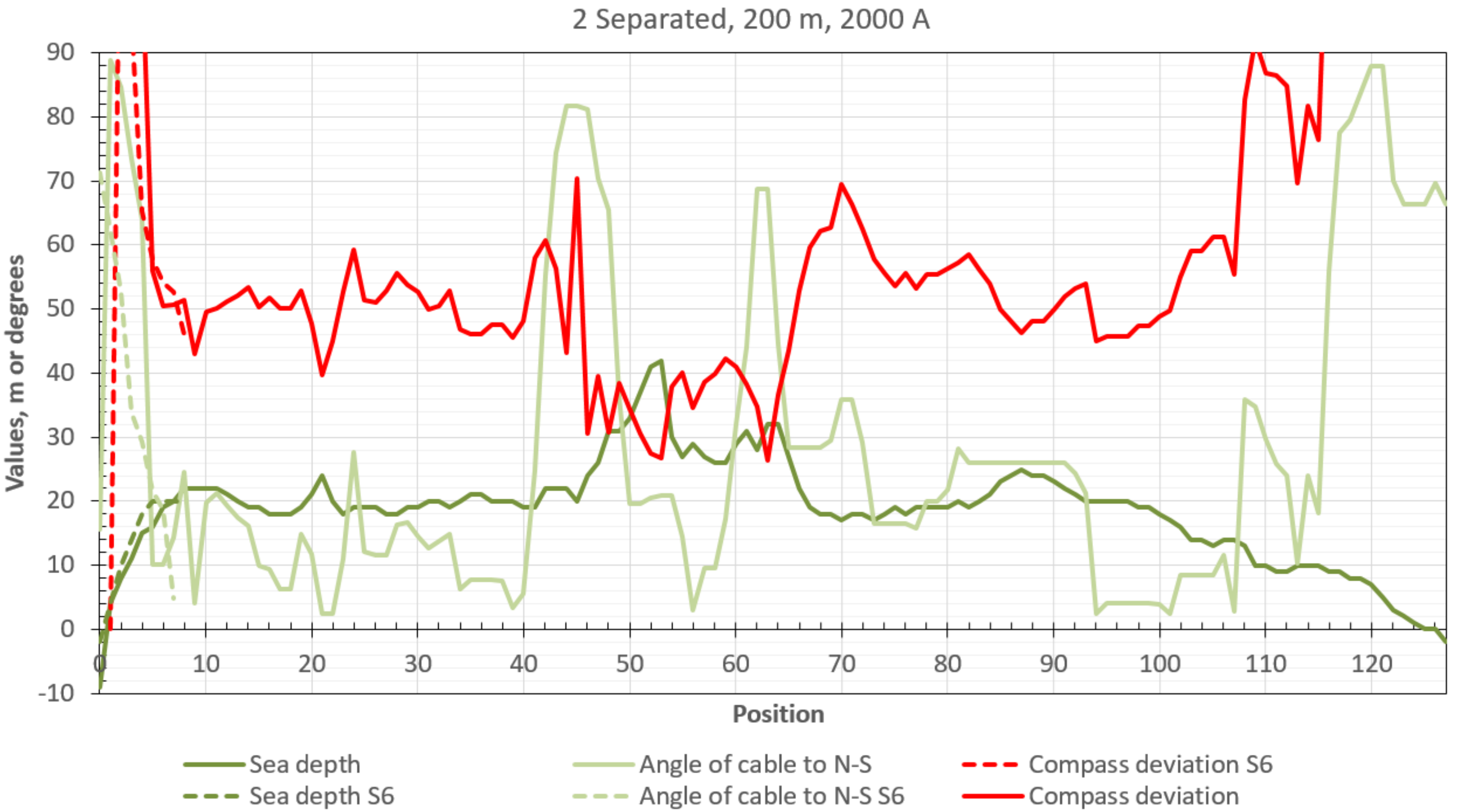


Figure A4: Calculated compass deviations for Sea Link with bundled two cable design with metallic return. Compass deviations at sea level were calculated along the entire route using the depth to seabed and cable angle to vertical for each station mark. Spot calculation were along performed to test validity of automated approach.

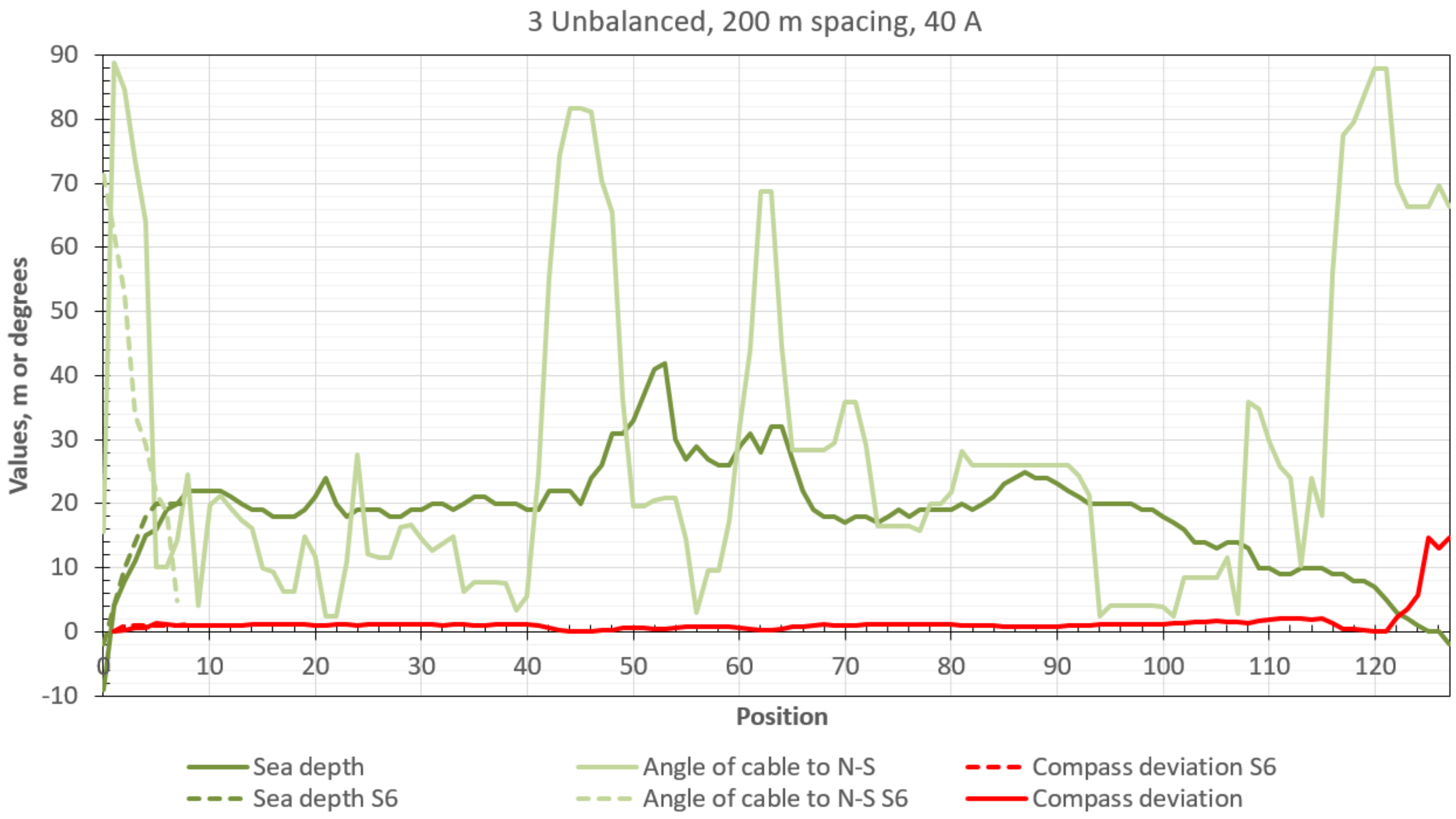
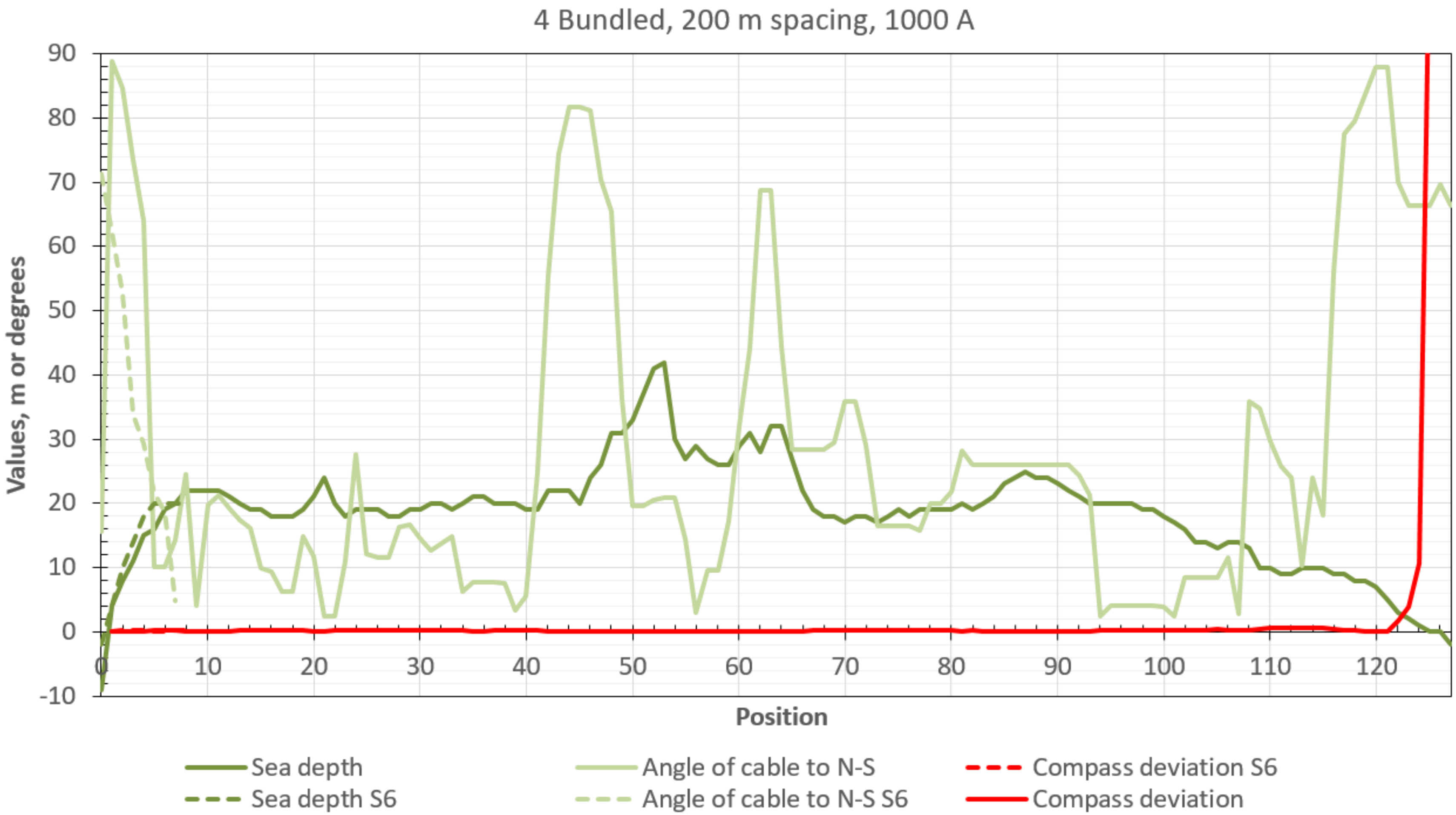


Figure A5: Calculated compass deviations for Sea Link with bundled four-cable design. Compass deviations at sea level were calculated along the entire route using the depth to seabed and cable angle to vertical for each station mark. Spot calculation were along performed to test validity of automated approach.



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