A.1 Introduction

Jacobs have developed a suite of numerical models of the study area to support the design process; these models provide the following inputs:

Wave and water level parameters that are essential for the design of coastal protection structures.

Information on the historical shoreline change and predicted future shoreline change if no additional coastal protection works are undertaken.

A.1.1 Phase 1 Baseline Modelling Overview

Baseline modelling was undertaken by Jacobs during Phase 1 of the project. This baseline modelling also included the effect of spatial and temporal changes in water level on waves and variable sediment transport rates.

A two-dimensional wave model of the East Coast of Ireland was set up to derive wave data at nearshore points along the study area. This model uses wind and wave data recorded in the Irish Sea by the Irish Marine Data Buoy Observation Network and the UK Met Office and bathymetry information from INFOMAR and C-MAP to predict the wave heights, periods and direction close to the shoreline.

The baseline modelling of the shoreline looked at locations of interest between Dublin Bay and Wicklow Harbour to estimate the quantity of beach sediment moving along the coast and to predict the future shoreline position in 2055 and 2100. The results of this modelling highlight the areas of the railway which are most at risk of erosion. The baseline shoreline modelling does not include CCA5 as this type of model is unsuitable due to the presence of rocky cliffs around Bray Head and a very thin beach over clays at Greystone North Beach.

A.1.2 Phase 2 Modelling Overview

Under Phase 2 of the project, modelling of the stable beach profile between the rock armour headlands proposed under Option A in CCA5-B has been undertaken estimating the equilibrium bay shape. This model calculates the equilibrium position of the mean sea level contour between two fixed points under the predicted wave climate. Similarly, this model was used to determine the stable beach under the groyne and beach Option B for CCA5-B.

No further modelling has been undertaken in CCA5 due to the rocky nature of the shoreline in CCA5-A and the thin beach in CCA5-B.

A.2 Waves and Water Levels

The nearshore points for CCA5 are shown in Figure A.2-1.

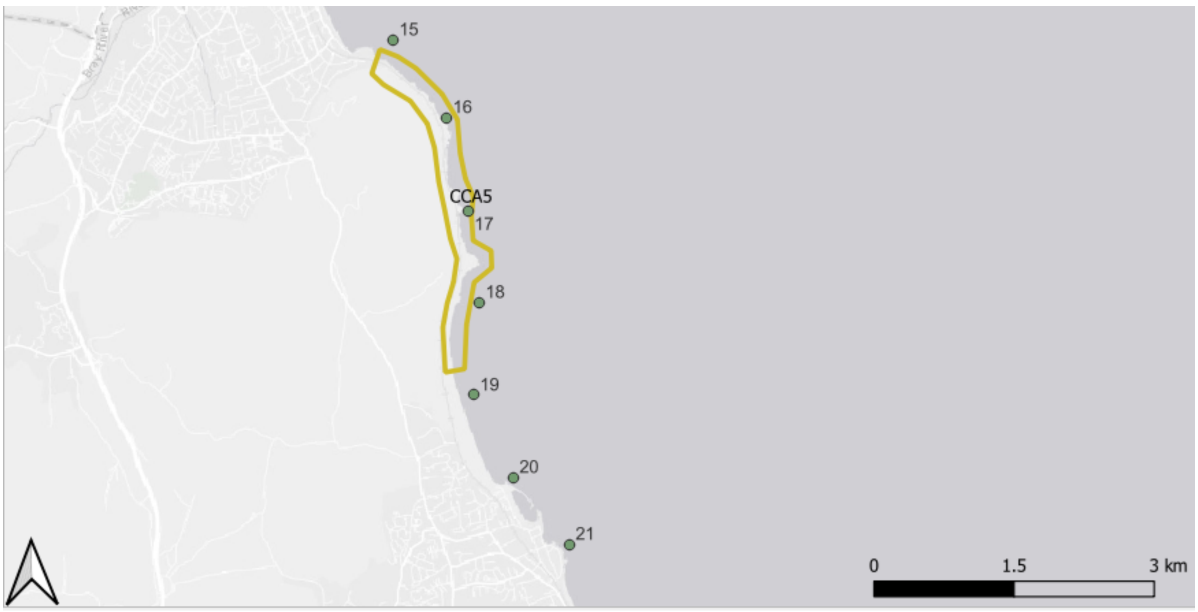


Figure A.2-1. Nearshore Points around CCA5

A.2.1 Waves

Figure A.2-2 provides an example output of the regional wave model for offshore waves approaching from the northeastern sector (55°N).

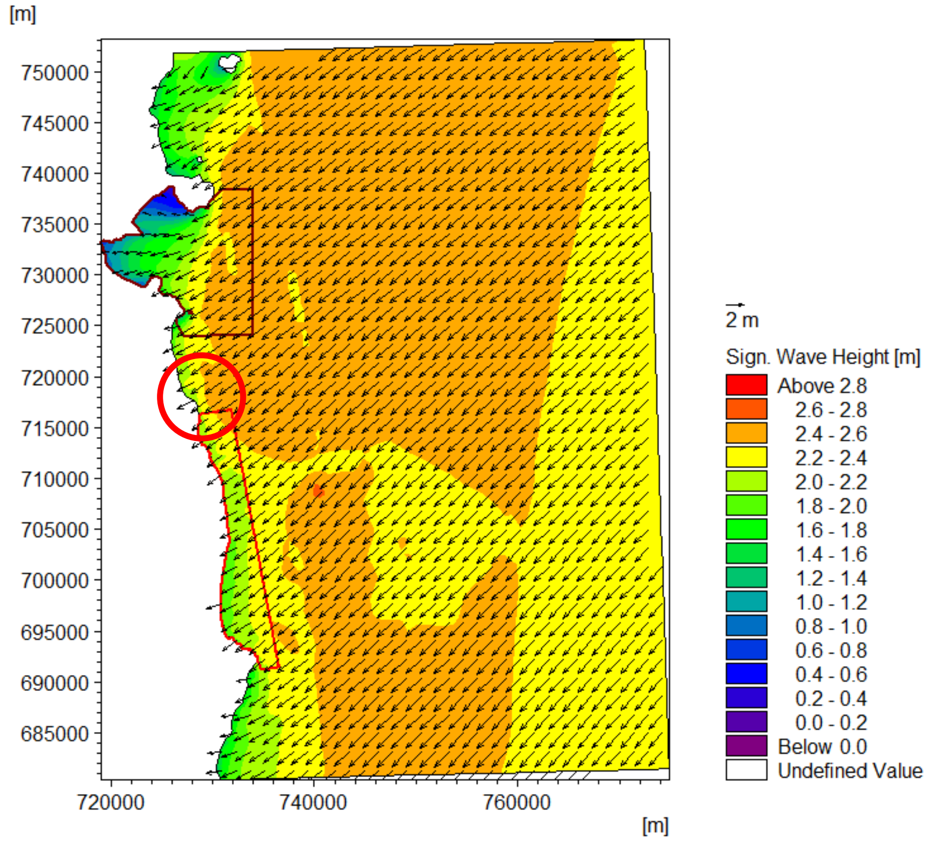


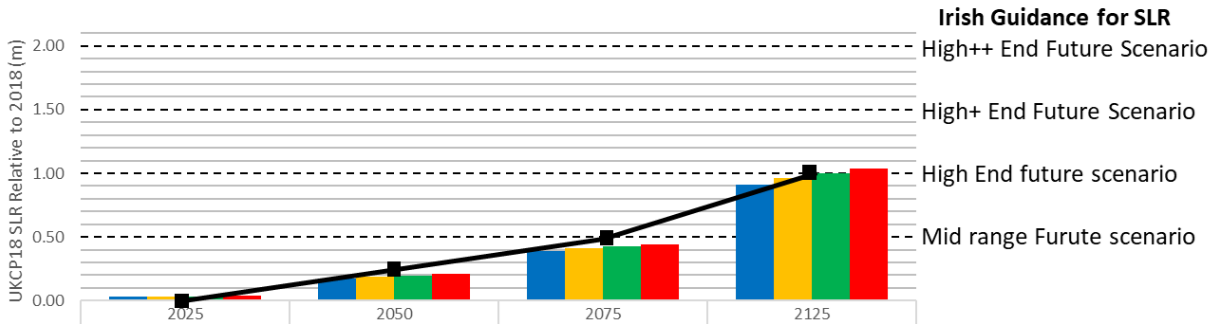
Figure A.2-2. Representative wave heights (MWD 55°N); CCA5 location is circled in red

A.2.2 Water Levels

A.2.2.1 Sea Level Rise

The following sea level rises have been adopted on consideration of Irish (OPW) and UKCP18 guidance. These are plotted against the guidance in Figure A.2-3.

- Present day (2025) = +0.00 m
- Year 2055(P + 30 yrs) = +0.30 m
- Year 2075 (P + 50 yrs) = +0.50 m
- Year 2125 (P +100 yrs) = +1.0 m



	2025	2050	2075	2125
53.94 -6.08	0.03	0.18	0.39	0.91
53.28 -4.75	0.03	0.19	0.41	0.96
52.72 -4.75	0.04	0.20	0.43	1.00
52.06 -5.25	0.04	0.21	0.44	1.03

Figure A.2-3. Comparison of UKCP18 sea level rise projections and Irish Guidance. Proposed SLR curve shown with black line

A.2.2.2 Tidal Levels

Admiralty TotalTide (ATT, 2023) water levels have been extracted for the Irish Sea covering the extent of the modelled area (Figure A.2-4). The levels for Dublin North Wall and Wicklow Harbour are summarised in Table A.2-1.

Table A.2-1. Tide levels for Dublin North Wall and Wicklow Harbour

Tidal Level	Dublin North Wall (mODM)	Wicklow Harbour (mODM)
Highest Astronomical Tide	+1.99	
Mean High Water Springs	+1.59	0.19
Mean High Water Neaps	+0.89	-0.21
Mean Sea Level	-0.11	
Mean Low Water Neaps	-1.01	-1.41
Mean Low Water Springs	-1.81	-1.81
Lowest Astronomical Tide	-2.61	

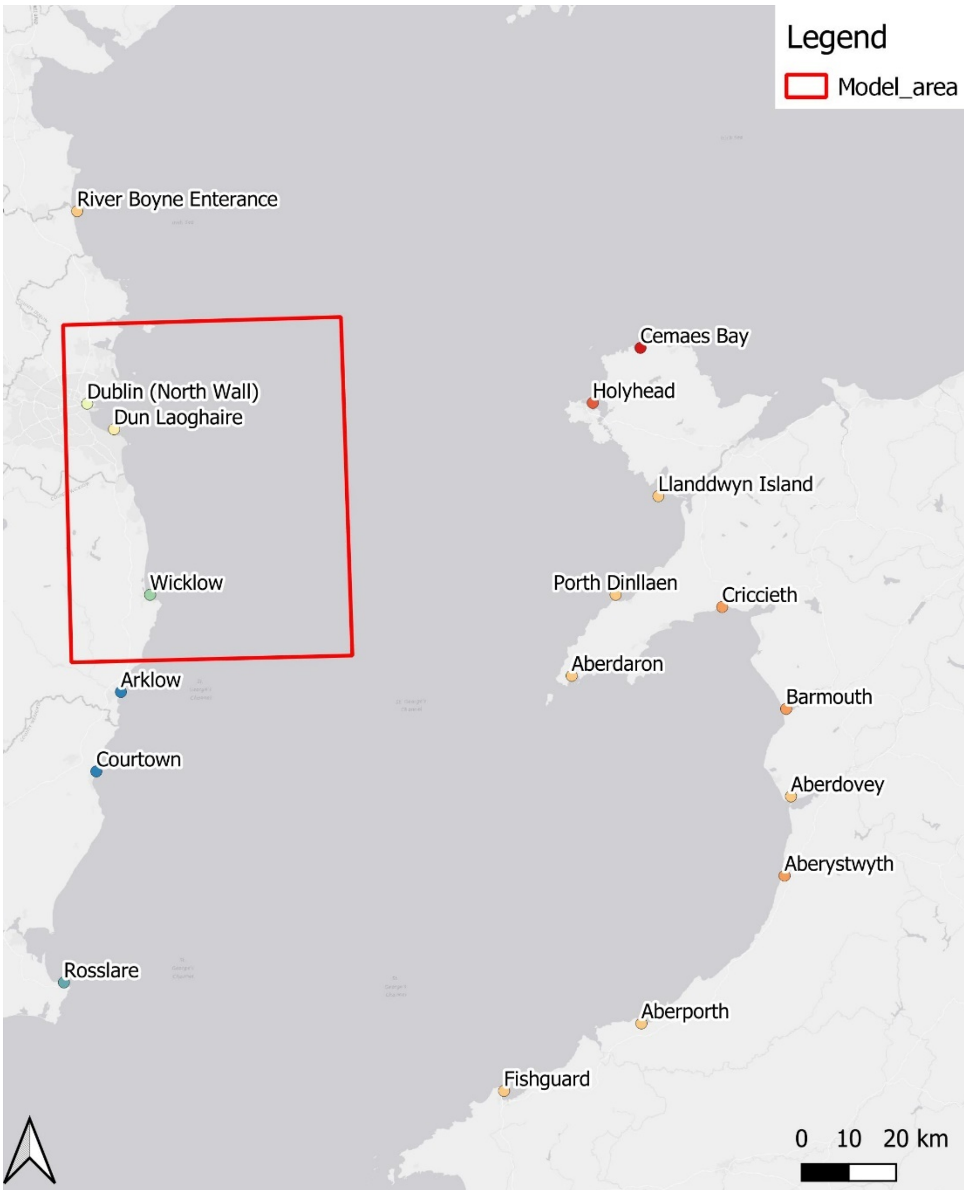


Figure A.2-4. Admiralty Total Tide data locations and model area

A.2.2.3 Extreme Water Levels

Extreme water levels are available along the Irish coast from the Irish Coastal Wave and Water Level Modelling Study (ICWWS, 2018), and along the Welsh coast from the Coastal Flood Boundary (CFB, 2018) dataset. Both sets of data are used to provide boundary conditions to the general ECRIPP model. Water levels at 39 locations from Dublin Bay to Wicklow Harbour have been extrapolated using these input data.

A.2.3 Joint Probability of Waves and Water Levels

Joint probability analysis combines the likelihood of two different variables occurring at the same time. In the design of coastal structures, it is common to use joint probability pairs of wave heights and water levels; this provides the design team with several different inputs which have the same chance of occurrence to fine-tune the design against. Figure A.2-5 shows the joint probability results for the 1 in 2 and 1 in 200 year return period conditions in the present day, 2055, 2100 and 2125. The left hand panel contains the conditions at nearshore point 17 and the right hand panel contains the offshore conditions.

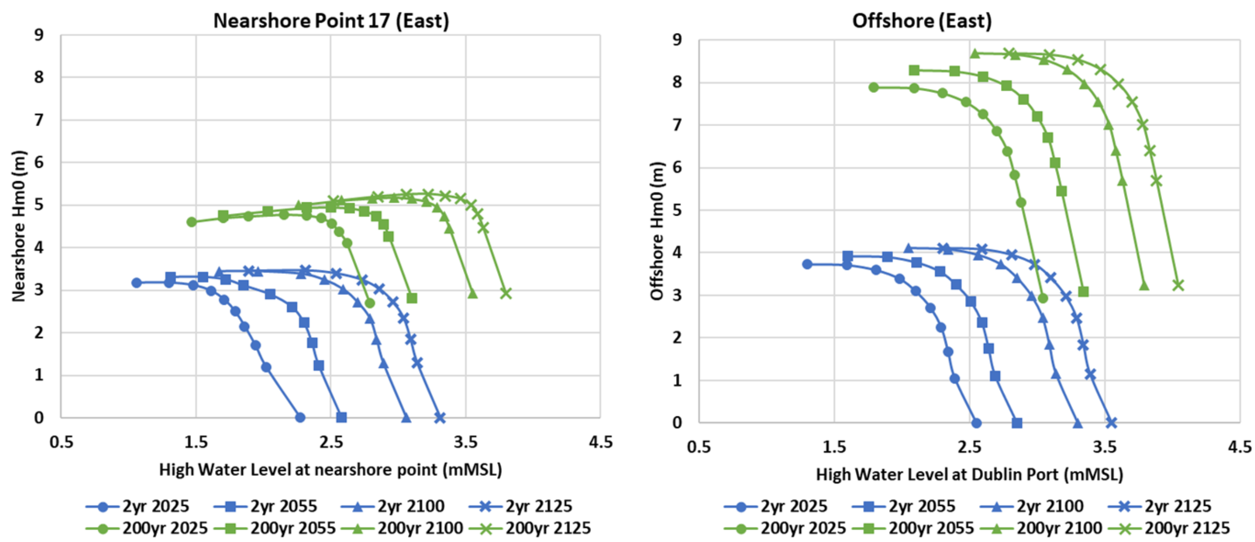


Figure A.2-5. Joint probability plots of wave height (y-axis) and water level (x-axis) at nearshore point 17 and offshore for the 1 in 2 and 1 in 200 return period conditions in the present day and with sea level rise.

A.3 Bay shape modelling

The CCA5-B option A and B comprises rock headlands and groynes, respectively. In Option A, the main function of the headland structures is to protect the area on the lee side of the structures, allowing for some controlled erosion in the unprotected areas. In Option B, the groynes have the function to hold a beach, reducing the waves reaching the cliffs, and consequently, reducing erosion. Option B also comprises beach nourishment.

To evaluate the best structures arrangement, beach equilibrium shape analysis was undertaken for both options, which defines the alignment that the beach will tend to, reaching an equilibrium when there's minimal sediment transport for the dominant wave direction. This alignment might temporarily change, due to seasonality wave condition change or due to storms. This analysis informs the expected cliff erosion between the headlands for Option A and the required length and position of the groynes to hold the design beach profile and the expected beach alignment for Option B.

A.3.1 Equilibrium Bay Shape

the equilibrium bay shape was modelled using the software Coastal Modelling System (SMC), based on Hsu & Evans, "Parabolic Bay shaped and applications" (1989) formulation.

The beach control structures (e.g groynes) diffract the oncoming waves, reducing their height and changing the wave direction adopting a parabolic shape on the lee side of the structure. This effect is commonly noticed in closed bays and shapes the equilibrium beach. Outside of the zone of influence of the control structures, the beach adopts a direction perpendicular to the wave direction. Where two zones of influence overlap, the beach adopts a shape in between the two lines.

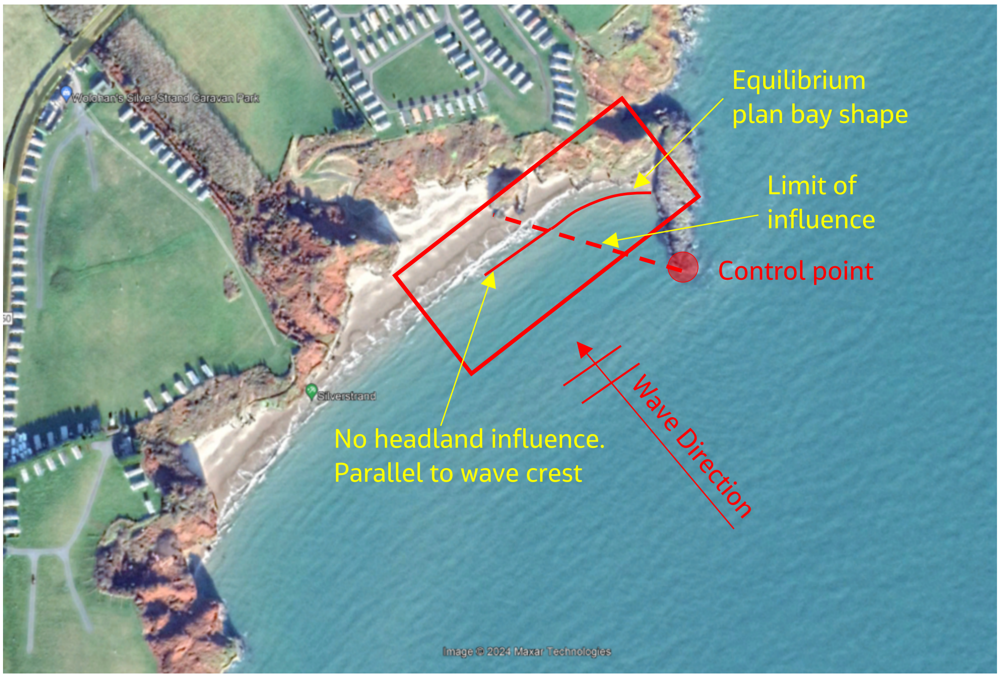


Figure A.3-6. Parabolic bay shape example. Imagery from Google Earth (06/01/2020), 2024 Maxar Technologies.

A.3.2 Main parameters

The main parameter for equilibrium bay shape analysis is the wave direction.

At CCA5-B, the wave direction in the two nearshore wave points varies (approximately 200m from shore) between 65 and 70 degrees from North. However, in the north part of this frontage, the cliffs are rotated towards the east and given it's eroding nature, it was assumed that the predominant direction in the northern extent of CCA5-B is **90 degrees** (east), **rotating to 70 degrees in the southern area**, following the current alignment of the frontage.

At CCA5-B, there is one sediment sample, with sediment size of 1.6 and 35mm, which is characterised as shingle, but gives a wide range of typical sediment size. From visual inspection, it was defined the typical beach material as shingle and assumed the predominant material size between 5 and 10mm. The Beach Management Manual (CIRIA C685, 2010) provides typical beach slopes for varying sediment sizes, as shown in Table A.3-2 below. **For CCA5-B, a beach/ typical sediment slope of 1 in 10 was assumed.** This corresponds to an average slope for a shingle.

Table A.3-2. Typical beach slopes for various mean sediment sizes (Table 14.4 in Beach Management Manual (CIRIA C685, 2010).

Sediment type	Median sediment size	Mean beach gradient	
	D_{50} (mm)	*From*	*To*
Sand	0.2 0.3 0.5	1:50 1:25 1:20	1:100 1:50 1:40
Shingle	5.0 10.0 35.0	1:8 1.7 1:4	1:15 1:12 1:8

A.3.3 Option A – Headlands

CCA5-B Option A comprises three headlands that directly protect the cliff on the lee side, while allowing for some controlled erosion in the unprotected area. A headland is positioned directly in front of the tunnel entry where there's a drainage outlet and is a location of concern.

To define the future line of recession, it was assumed the foreshore will erode to MLW level, approximately -2mODM, at the headlands. To obtain the most landward position of the eroding cliffs, HAT was modelled, at approximately +2.0mODM. It was then defined a distance form centre of headlands to the modelled equilibrium bay line of 60m, with 40m (1 in 10 slope from -2 to +2mODM) plus an allowance of 20m, corresponding approximately to half of headland cross section accounting for the MLW to be located on the landward side of the structure.

To define the headland locations and length, the length outside of the zone of influence of the headlands was minimised, where there is no wave diffraction and no wave energy reduction.

Figure A.3-7 shows the SMC bay shape results. The blue lines represent HAT as the estimated future cliff alignment. The thicker pink lines define the end of the area of influence of each control point (headland). The black lines show the designed headland locations. For concept design it was defined three headlands with varying lengths between 150 and 330m.

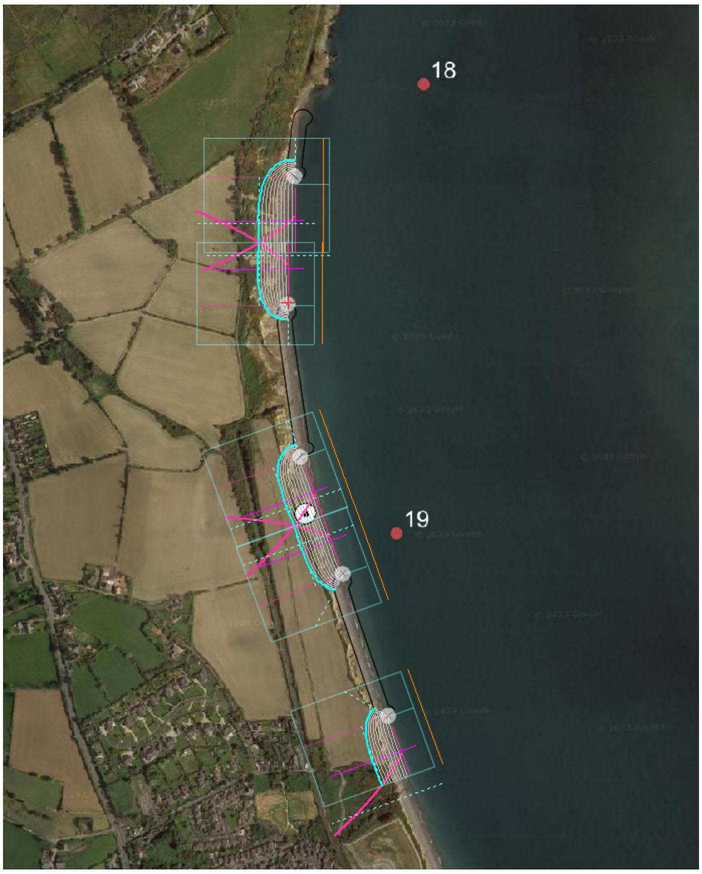


Figure A.3-7. SMC bay shape results for Option A.

A.3.4 Option B – Groynes and beach nourishment

CCA5-B Option B comprises five groynes positioned along this frontage with beach nourishment. These structures will protect the cliffs from eroding by breaking the waves and limiting the wave run-up to the beach profile.

Similar to Option A, the beach toe at MLW level, approximately -2mODM and a beach slope of 1 in 10 was defined. From run-up and overtopping analysis, a beach crest level of +5.8mODM and 35m width was defined, to reduce the waves reaching the back of the beach and eroding the cliffs.

Using SMC, the groyne locations were defined with control points and the beach equilibrium line at the crest level was obtained, approximately 80m from the groyne. The back of the beach equilibrium line was also obtained, at 115m from the control point. The groynes were then positioned to limit, at the back of the beach, the extent outside of the zone of influence of the groynes. This constraint was relaxed at the southern extent where the railway is further from the cliff.

Figure A.3-7 shows the SMC bay shape results. The blue lines represent the beach crest and back of the beach equilibrium lines. The thicker pink lines define the end of the area of influence of each control point (groyne). For concept design five groynes with varying lengths between 150 and 330m are proposed.

Figure A.3-8. SMC bay shape results for Option B.

A.3.5 Concept Design layout

Figure A.3-9 shows the concept design layout for Option A and B based on the results from the SMC analysis. The groynes lengths and final position were adjusted to ensure that beach design profile is within the extent of the groyne.

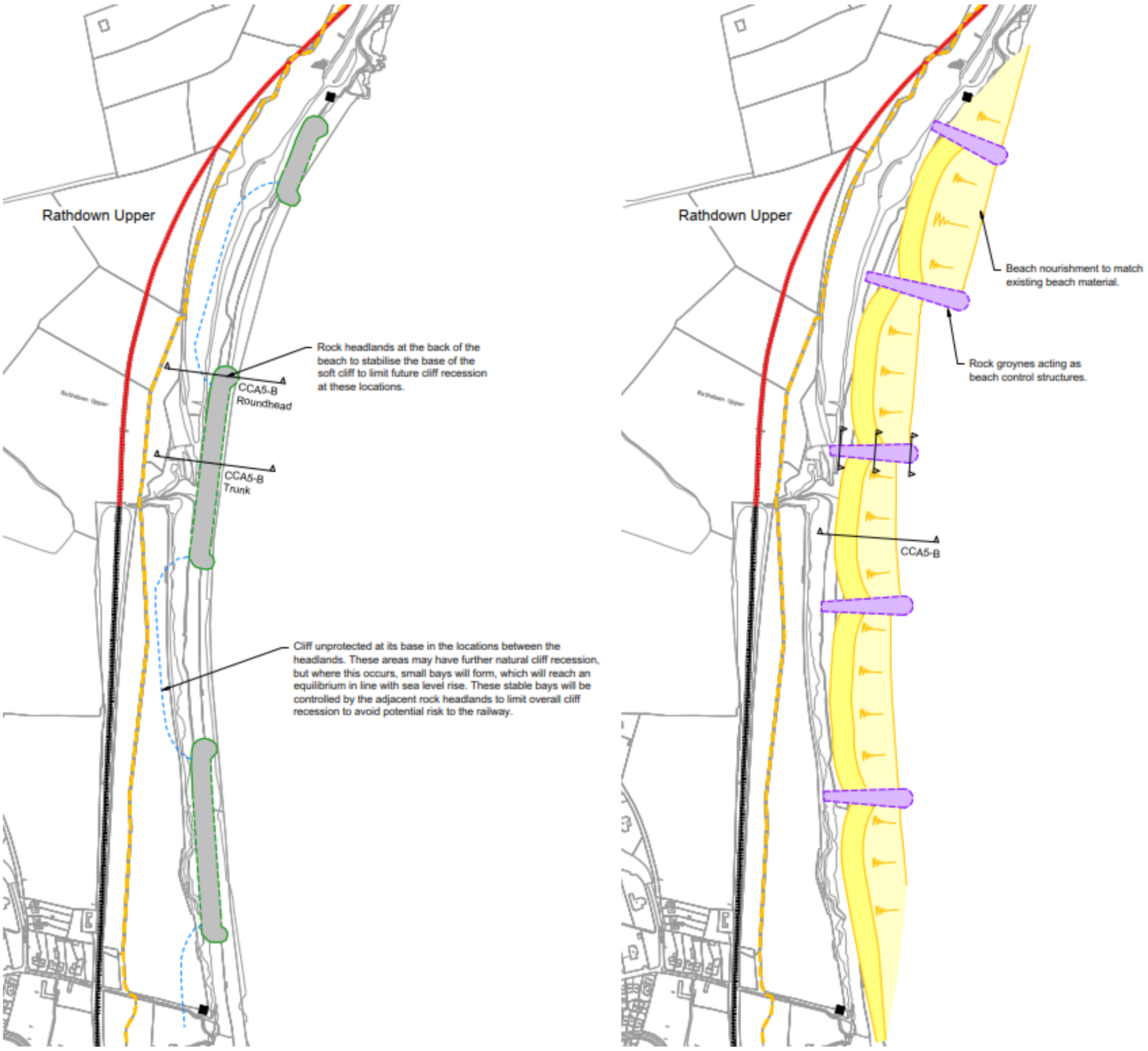


Figure A.3-9. CCA5-B Option A Headlands and future cliff line (left), and Option B Groynes and equilibrium beach (right) (adapted from Drawing 7694-CCA5-P2-DWG-CV-JAC-0110 Revision B)

A.4 Summary

Waves within CCA5 are large, with wave heights of 4 to 5m expected at the nearshore wave points. With climate change, small increases in wave height are predicted. Sea level rise of 1m over 100 years is expected; this will have a limited effect on the design of options as the railway is located well above the predicted water levels.

Equilibrium bay shape analysis was done to estimate the future cliff alignment and the headlands layout in option A and to define groynes layout and estimate the equilibrium beach shape in Option B.