Research Brief

Rail Safety & Standards Board

Impact of climate change on coastal rail infrastructure

Introduction

The effects of climate change, and in particular sea level rise, are likely to increase the severity of the wave, tidal, and wind effects on coastal and estuarine defences. In order to maintain railway assets and to deliver reliable performance to passengers and freight, it is important to measure the impact climate change will have on railway coastal infrastructure so that informed management decisions can be made about the most effective deployment of limited resources.

Figure 1: Wave overtopping along the Dawlish frontage

Aims

The aim of the project was to develop a methodology that could be used to assess how the effects of climate change would impact coastal and estuarine defences. This could be used to inform any future investment and engineering decisions. RSSB contracted Mouchel Parkman to carry out these investigations and worked closely with the Environment Agency throughout the project. The rail infrastructure in the Dawlish area of Devon was studied, to provide a basis for assessment of other coastal and estuarine defences.

The general methodology may also be applicable for the assessment of other infrastructure assets vulnerable to climate change.

Figure 2: King Harry's Walk, north of Dawlish Station

Approach

Survey

A topographic survey was undertaken of 15 typical cross-sections to define the

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structural dimensions of the defences, including the toe and crest levels and the beach/estuary profile in front of each defence. A structural assessment of each of the typical sections was also undertaken at the same time.

Numerical modelling

The present day offshore wave conditions were modelled using the average conditions from the last 15 years (1991 to 2006) and they were then used to predict wave conditions at five nearshore locations by the application of numerical modelling techniques. Wave conditions were established at the toe of the coastal defence structures and at the mouths of the Teign and Exe Estuaries. A spreadsheet was then developed to calculate overtopping at each of the selected structure sections. The offshore bathymetry and offshore and near shore data points are shown in Figure 3.

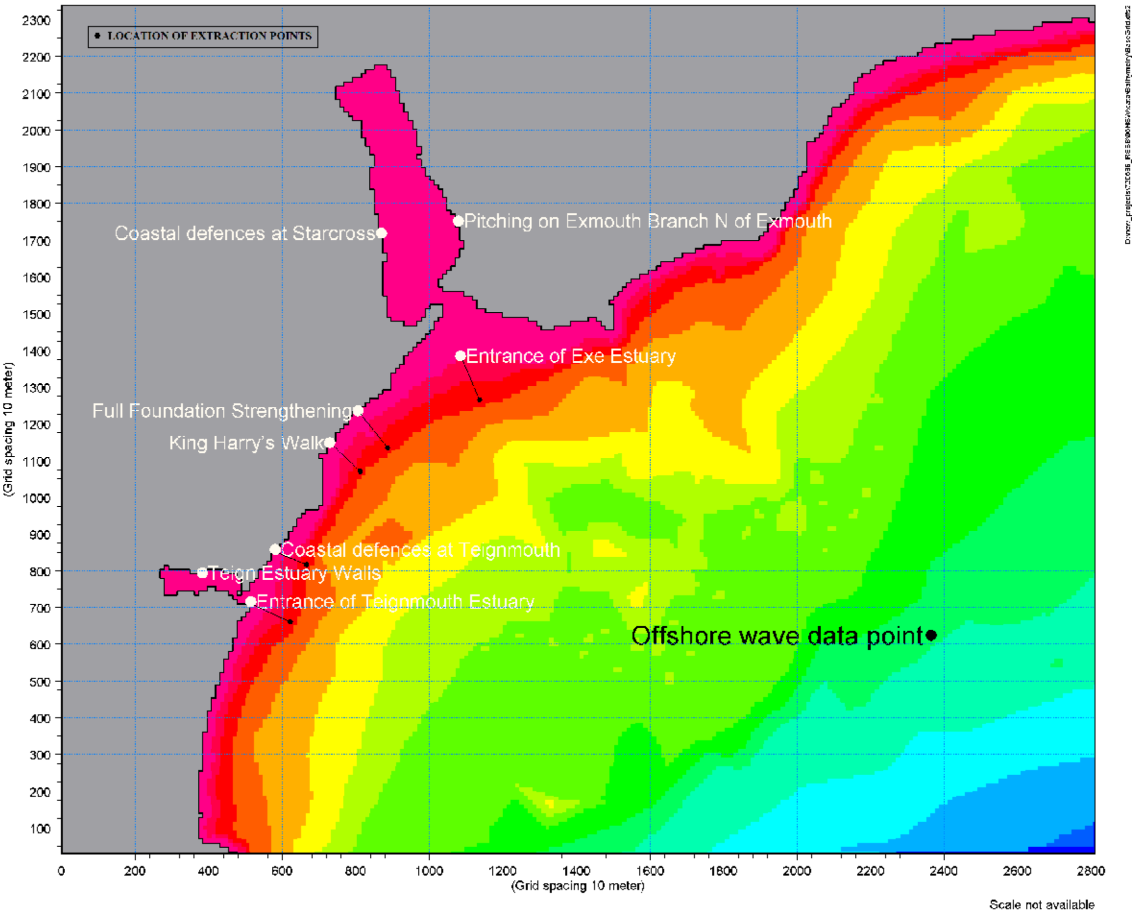

Figure 3: The offshore bathymetry and data points used for this research

Wave overtopping modelling

Wave overtopping represents the condition where water comes over the top of the defences. Coastal defence sections (see location plan in figure 3) were selected as representative of the sections most vulnerable to overtopping.

Extreme wave characteristics were established from estimates of wave height and sea level. The probability that extreme maximum wave height will coincide with extreme maximum sea level is uncertain. This situation occurs under tropical hurricane conditions (the

Caribbean for example) but is less likely to occur along the UK coastline. The relationship between extreme wave height and sea level may also change as a consequence of climate change.

A range of results was examined, taking account of estimated extreme sea levels coincident with estimated maximum and minimum wave heights. The actual wave height and coincident sea level are likely to fall somewhere between the two extreme cases.

These two extreme cases are thought to provide a good upper and lower bound to the design envelope and thus provide a good sensitivity analysis of the wave heights and overtopping likely to occur at the selected sites both for the present day (2006) and in the 2020s, 2050s and the 2080s.

Figure 4: Wave overtopping at King Harry's Walk during strong winds

Factors affecting sea level at the coastal and estuarine defences

The extreme maximum sea level at a coastal or estuarine defence is primarily dependent upon the astronomical tide and the storm surge. The storm surge is a combination of air pressure (low air pressure = higher water level), and wind speed and direction pushing water towards the coast and into estuaries. To a lesser extent, water level is influenced by the water level set-up of the waves. Wind speed and direction are therefore key factors influencing both the storm surge and the wave height. Long term changes in these extremes are driven by climate change and changes in relative sea level due to vertical land movement.

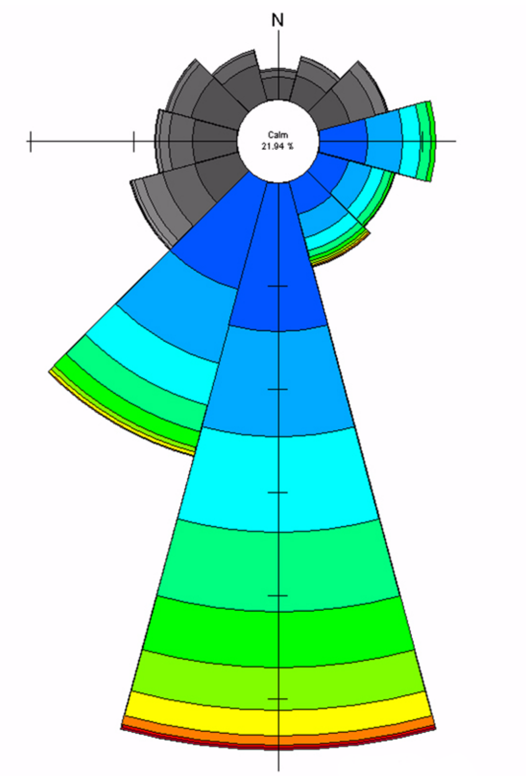

Figure 5: Wave rose for King Harry's Walk - illustrating the variation in wave height with wind direction

The aspects of climate change that contribute to a rise in extreme water level are the overall sea level rise and an increase in wave height and storm surge (for example due to increased storm intensity).

Findings

Predicted effects of climate change

The Met Office Hadley Centre has provided predictions of the effects of climate change on sea level and wave height for the 2020s, 2050s, and the 2080s at Dawlish, compared to the present day.

Low and high estimates of maximum extreme wave height, for storms that might occur once every year and once every 100 years, are summarised in Table 1.

Table 1: Predicted maximum extreme wave height at the toe of King Harry's Walk defences

Storm frequency (years)	Present day (2006)		2020s		2050s		2080s	
	Low (m)	High (m)	Low (m)	High (m)	Low (m)	High (m)	Low (m)	High (m)
1	1.04	1.26	1.12	1.33	1.19	1.41	1.27	1.48
100	1.14	1.79	1.22	1.86	1.30	1.94	1.38	2.02

Low and high estimates of maximum sea level coincident with maximum extreme wave height, for storms that might occur once every year and once every 100 years, are summarised in Table 2.

Table 2: Predicted maximum sea level coincident with maximum extreme wave height at the toe of King Harry's Walk defences

Storm frequency (years)	Present day (2006)		2020s		2050s		2080s	
	Low (m)	High (m)	Low (m)	High (m)	Low (m)	High (m)	Low (m)	High (m)
1	2.19	2.61	2.34	2.75	2.48	2.90	2.62	3.04
100	2.32	3.52	2.47	3.67	2.61	3.81	2.76	3.96

Overtopping

Water overtopping the seawall, can give rise to disruption of trains and the potential for structural damage to sea defences and track.

Based on the mean of estimates of overtopping for all six coastal and estuarine defences (shown in figure 3), the results of the study indicate that, for the existing defence crest levels, and for a storm of any intensity, wave overtopping of the frontage could increase by around 50 percent in the 2020s, by more than 100 percent in the 2050s and by more than 200 percent in the 2080s.

To assess the potential range of overtopping scenarios, a sensitivity analysis has been carried out using high estimates for sea level (worst case scenario) coincident with low and high estimates of the maximum extreme wave height. Low and high predictions for the frequency of overtopping for the yearly storm event, are then obtained from analysis of the wave characteristics. These predictions of the percentage increase in overtopping at the King Harry's Walk sea defences, compared to present day (2006) values, are summarised in Table 3. Significant divergence does not become apparent until the 2080s.

Table 3: Predicted percentage increase in overtopping at King Harry's Walk

Prediction	2020s	2050s	2080s
Low	120	796	5592
High	115	812	8067

The yearly storm event results are indicative of the impact on the operation of the railway if the low or high predictions of extreme water level were to occur. They suggest that overtopping (relative to present day levels - 2006) would increase by around 120% in the 2020s, 800% in the 2050s and 6000% to 8000% in the 2080s, for low and high predictions respectively. The large increase is due to the exponential relationship between the environmental conditions, wave height, water level, and the overtopping volumes.

Impact on the operation of the railway

Flood action and storm response procedures are in place in the Dawlish area in order to minimise the risk to train operations as a result of water overtopping the sea defences and/or structural damage to the track and the defence structures.

Intervention procedures have been established according to storm severity. Incidents have been classified as:

- Level 1 - speed restriction and constant monitoring
- Level 2 - closure of the down line [which is the closer to the sea], additional monitoring and inspections
- Level 3 - total line closure until weather conditions permit resumption of normal service

Table 4 indicates the likely increase in frequency of Level 2 and 3 incidents compared to the mean of actual and predicted incidents for the present day.

Table 4: Number of predicted incidents per year

Incident	Present day mean (2006)	2020s	2050s	2080s
Level 1	6.4	No data	No data	No data
Level 3	1.2	1.3	2	2
Level 3	0.21	0.29	0.5	1

This analysis indicates that climate change is likely to cause progressively increasing disruption to trains and an increased risk of significant structural damage to the sea defences.

Implications for the structural integrity and design of the Dawlish to Teignmouth coastal structures and coastal defences in general

Generally coastal structures are designed to withstand waves generated by a 1 in 100 year storm event. An increase in the size of the predicted waves at the defence sites will not only reduce the residual life of the existing structures but will increase the size and strength requirements for future structures.

An increase in wave height results in an increased volume (discharge) of water over the defence, which causes disruption and structural damage in proportion to the height of water above the defence. Analysis of the increase in the predicted 1 in 100 year wave heights at the toe of the structure, will permit assessment of the likely impact of sea level rise on the structural integrity of the existing defences, and will permit determination of the design requirements for future replacement defences.

Furthermore, an analysis of the increase in the predicted 1 in 100 year wave energy at the toe of the structure, will provide a good indication of the increase in wave forces that the existing and future defence structures, are likely to be subjected to. An increase in wave energy will have an adverse impact on the future maintenance and also on asset integrity.

For the three defence sections along the Dawlish to Teignmouth Coastal frontage (see figure 3), the results of analysis has indicated:

- an increase in the 1 in 100 year wave height in the 2020s of up to 9%
- a corresponding increase in wave energy of up to 18%
- an increase in the 1 in 100 year wave height of up to 25% by the 2080s
- a corresponding increase in wave energy of up to 57%

The vulnerability of existing and future coastal defence structures to the predictions of sea level rise, is further illustrated by the consequent decrease in the return period of the current 1 in 100 year design wave height over time. It was predicted that the return period of the present day (2006) 1 in 100 year design wave height would reduce to 1 in 40 years in the 2020s, 1 in 25 years in the 2050s and 1 in 14 years in the 2080s. This demonstrates the vulnerability of the current defences to sea level rise if they are not renewed to an even more robust standard.

In the absence of a change in the design specification, this work predicted that, due to wave overtopping, the frequency of disruption to services and the rate of asset deterioration, will increase.

Next Steps

The research undertaken to assess the impact of climate change at Dawlish, has provided estimates of increased vulnerability to disruption of train services and the likelihood of damage to sea defences between the Exe and Teign estuaries. Network Rail will consider the results of this work in determining the short- and long-term management strategies for the maintenance and replacement of the Dawlish sea defences.

The research has demonstrated the application of a methodology, for assessing the vulnerability of sea defences to climate change, which may be applied to other sea defences. The general approach may be adapted for assessment of other asset types vulnerable to the effects of climate change.

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