MCCIP ARC Science Review 2010-11
Built Structures

Marine Climate Change Impacts Partnership

STEPHEN HUNT[1] AND JON REES[2]

[1]ABP Marine Environmental Research Ltd, Waterside House, Town Quay, Southampton, SO14 2AQ

[2]Cefas, Pakefield Road, Lowestoft, Suffolk, NR33 0HT.

Please cite this document as:

Hunt, S., and J. Rees (2010) Built Structures *in* MCCIP Annual Report Card 2010-11, MCCIP Science Review, 9pp. www.mccip.org.uk/arc

EXECUTIVE SUMMARY

The built marine environment includes a wide range of structures that could potentially be impacted by climate change in a number of different ways. For the purposes of this review the built environment has been split into offshore and coastal structures.

The design of structures is traditionally based on an analysis of comprehensive metocean parameters from which future extreme events are derived. With the uncertainties introduced by climate change this technique may become less effective at predicting future extreme conditions and the modelling of climate change impacts will need to be explored.

The impacts of climate change on marine structures are diverse and depend on the type of structure, its function and location within the marine environment.

100-year analyses of both mean and significant wave heights are typically used to inform design criteria for offshore built structures such as oil installations. These studies reveal a high degree of natural variability in wave climate, which makes interpreting the impacts of climate change on offshore built structures very difficult.

There is limited published evidence that climate change has led to the offshore industry having to adjust any operational practices over the recent past or the present day.

There is no published evidence that specifically relates climate change to impacts on coastal structures over the recent past or the present day. However, sea-level rise has affected the planning of coastal structures.

Overall expected impacts can be summarised as follows:

- Increases in wave energy and the frequency of storm events leading to greater stresses on both offshore and coastal structures and associated access and maintenance problems
- Changes in tidal currents leading to changing scour and erosion patterns around both offshore and coastal structures
- Increases in sea level and wave heights leading to more frequent overtopping of defences and flooding of the coastal zone

Based on the UKCP09 projections only, built structures located in the southern North Sea and the Irish Sea and North Channel regions will be impacted the most by changes in winter significant wave height.

Any reduction in the area of intertidal habitats (mudflats, saltmarsh) as a result of climate change would result in increased stresses on coastal structures as these natural defences tend to dissipate wave and tidal energy.

In addition, high value infrastructure exists on the coastline, such as power stations, ports, rail and road. These structures will have a requirement to be maintained into the future and consequently require a commitment to continued protection from coastal processes. Nuclear power installations in particular will require particularly long-term commitments as the life cycle of a power station is measured in centuries.

FULL REVIEW

For the purposes of this review, the built environment has been split into sections discussing likely impacts of climate change on structures out at sea (offshore) and on the water's edge (coastal).

1. What is already happening?

Offshore structures

Historically metocean (a commonly used abbreviation for meteorology and oceanography) parameters have been recorded at a number of oil installations, especially wave height and period. Analyses of wave climate data in the northern North Sea since 1973 (Leggett, 2007) has examined the link between regional scale variability in the wind field and changes to the wave height. A broad-scale feature of the timeseries of annual mean significant wave height was an increase from 1973 into the first half of the 1990s, following which it reduced. However, the behaviour over time of the autumn (Oct-Dec) and winter (Jan–Mar) wave heights has been different. These data suggest that significant wave heights have been reducing in the autumn since a peak in 1980-1985 whilst greater increases were seen in the winter in the first half of the 1990s. Both seasons show strong relationships, using 5 year rolling means, to their respective North Atlantic Oscillation (NAO) index suggesting the link to the regional scale wind field. These results from the industry data broadly mirror those in the academic literature (see MCCIP Storms and Waves submission). Importantly these data are used to assess the 100-year returns for average waves and peak waves which are then used as part of the design criteria for new structures. These values are seen to be sensitive to the length and timing of the datasets on which they are based. Calculated on the wave data from 1988 to 1996, when waves heights in winter were at their highest, the 100- year significant wave height would be 17.5 m, rather than the 15.6 m now used in design criteria for the northern North Sea based on the longer data set from 1973-1998 (Leggett, 2007).

However, analysis of the wave climate over a 200 year timescale using NAO records to infer extreme wave events from the North Atlantic off Norway indicates that extreme wave events before 1960 were significantly more severe than those experienced since (Taylor *et al*., 2009). This shows the difficulty in attributing anthropogenic climate change to severe wave events and highlights the need for long period records and robust statistical analysis of the highly variable wave height records. Furthermore, this also illustrates the difficulty in interpreting the impacts of climate change against a variable baseline regime.

There is limited published evidence that climate change has led to the offshore industry having to adjust any operational practices over the recent past or the present day.

Coastal Structures

There is no published evidence that specifically relates climate change to impacts on coastal structures over the recent past or the present day. However, sea-level rise has affected the planning of coastal structures.

2. What could happen in the future?

Offshore structures

Offshore structures include those used as part of the oil and gas industry and increasingly the renewables sector such as offshore wind farms. Despite the importance of the oil and gas industry and the increased development of renewable energy there are no known published sources of data describing the predicted impacts of climate change on offshore structures.

Oil and Gas

The majority of oil and gas platforms are situated in regions 1, 2 and 5 with some in region 7. Overall the offshore industry could be vulnerable to both changes in sea level and increases in waves and winds, leading to greater stresses on structures in the marine environment. Changes to currents could result in changes to scour around the legs and supports of offshore installations.

Changes in storminess could also affect access to offshore installations and pose operational issues in terms of health and safety. There is no published evidence that discusses the reduction in operational time that could be expected with climate change. Any reduction in maintenance windows will require increased reliability and automation of offshore installations.

The UKCP09 predictions (which are based on a medium emissions scenario) indicate that the winter significant wave height will decrease in regions 1 and 7 and increase in regions 2 and 5. This indicates that the oil and gas installations in the Irish Sea and the Southern North Sea will experience the biggest impacts with respect to changes in winter significant wave height under a medium emissions scenario. Changes to currents are difficult to predict and vary from area to area and therefore it is not possible to suggest how climate change might impact on these processes. Considering the relatively short life cycle of offshore oil and gas platforms (c.50 years) it is unlikely that the impacts of climate change will pose a significant threat to installations that have already been built.

Renewables Industry

In terms of development, the most advanced of the offshore renewable sectors is wind energy, with wind farms planned for regions 1, 2, 3, 4, 5 and 6. Wind farm development is particularly concentrated in the Irish Sea and the Southern North Sea (regions 2 and 5) where a number of round 1 and 2 wind farms have been or are under construction. Impacts on wind turbines are likely to be similar to those described for the oil and gas industry and overall could be vulnerable to both changes in sea level and increases in waves and winds, leading to greater stresses on structures in the marine environment. Changes to currents could result in changes to scour around turbine foundations.

It is also possible that changes in storminess could affect access to offshore wind farms and pose operational issues in terms of health and safety during construction and maintenance. As for the oil and gas sector, there is no published evidence that discusses the reduction in operational time that could be expected with climate change. Any reduction in the maintenance windows will require increased reliability and automation of offshore wind farm structures.

UKCP09 suggests that in terms of significant wave height, it is likely that wind farms in the southern North Sea and the Irish Sea will be most affected by increases in wave energy. Wind farms that are being constructed during rounds 1 and 2 are predominantly built on relatively shallow areas of seabed and therefore are potentially more prone to changes in bedload transport than those built in deeper water during round 3. However, this depends greatly on the seabed morphology and any changes to sediment transport are difficult to predict and will be localised in nature. Considering the relatively short life cycle of offshore wind farm turbines (c.50 years) it is unlikely that the impacts of climate change will pose a significant threat to installations that have already been built.

Tidal barrages situated closer to the coast in estuaries and embayments will also be prone to increased storminess and sea level rise. Increased storminess will put additional stresses on barrage structures and sea level rise could lead to the overtopping and flooding of the structures. Tidal barrages need to be designed to account for probable rises in sea level to avoid the overtopping and flooding of these structures later in their lifetimes. In addition tidal barrages impact on tidal regimes and as such these impacts will need to be considered in the context of future climate change.

Submarine cables

Submarine cables are used both in power transmission and the telecommunications industry. Within the renewables industry, cables are required for both the inter-array connections (between the turbines) and to connect the grid to shore. Telecommunications cables are laid over many miles and therefore a greater proportion of the cable length is offshore in deeper water, and hence tends to be beyond the influence of sediment transport caused by wave and current activity. Although submarine cables are present throughout the UK, there is a large density of telecommunication cables that make landfall in the southwest (region 4). Power transmission cables tend to be restricted to shallower and coastal waters and are distributed throughout the UK.

Generally cables are laid in two different ways. Firstly, cables laid in water shallower than 1500m tend to be buried and this gives them some degree of protection from activities such as anchoring and fishing which could break the cables (ISCP, 2009). Cables are also protected by a geographical buffer which restricts activity in the surrounding area (ISCP, 2009). Cables deeper than 1500m tend to be left on the surface as there is less risk of breakage (ISCP, 2009). Cables in shallow water are around 50mm in diameter as they have a protective outer layer, whereas cables in deeper water are not protected and therefore are only 17–20mm in diameter (ISCP, 2009). This means that cables in shallow water will not be prone to scour at the surface but could be prone to becoming exposed leading to a possible breakage in areas of high sediment mobility. Changes in the current regime could result in an increase in the frequency of this occurrence in some areas.

If storms become more severe it is possible that suitable weather conditions for laying cables could change. Adaptation measures could include the deeper burial of cables in regions of high risk and the reinforcing of cables to prevent breakage. There is no published work that describes climate change impacts on the cables.

Based on the UKCP09 report it is likely that the impacts of waves will be greater in regions 2, 3, 4 and 5. Impacts will be restricted to shallower sea where the effects of waves will be greatest on the seabed.

Pipelines

The majority of pipelines in UK waters are associated with the offshore fossil fuel industry and therefore most pipelines are situated in the north (regions 1 and 7), the Southern North Sea (region 2) and the Irish Sea (region 5). In common with other offshore structures, there are no published literature sources detailing the potential affects of climate change on pipelines.

It is possible that climate change could impact on both the installation and maintenance of pipelines. Increases in the frequency and severity of storms could lead to smaller weather windows suitable for pipeline installation. Once the pipelines are installed changes in patterns of erosion and currents could lead to increased scour on the seabed, exposing buried pipelines leading to risk of breakage.

Pipelines can measure up to 900mm in diameter and are rigid; because of this unburied pipelines can be susceptible to buckling as a result of vertical currents. Therefore increases in current speed that do not cause scour could cause pipeline breakage.

There is no published evidence of any adaptation measures related to climate change. In the future, it could be necessary to restrict pipe laying to certain times of the year to allow safe installation of pipelines. Sediment modelling studies may become a requirement to ensure that pipelines do not become exposed on the seabed. If changes to currents and temperature cause pipeline buckling, it could be necessary to adjust the tolerances of the material used. Detailed studies examining suitability of materials under changes in sea temperature would be required. The use of alternative materials or the requirement to bury the pipelines would lead to an increase in cost of laying pipeline.

Based on the UKCP09 report it is likely that the impacts of waves will be greater in regions 2 and 5. Impacts will be restricted to shallower seas where the effects of waves will be greatest on the seabed. Changes to currents are complex and difficult to predict and consequently should be considered on a site by site basis using detailed numerical modelling.

Derivation of design parameters

The design and operation of offshore structures in the UK is based on comprehensive records of metocean data used to calculate extreme wave, wind and water level events. Although the use of historic data provides an indication of the statistical probability of a past event reoccurring, it will be become important to take into account modelled future changes to water level, winds and waves as this will impact on the future design of offshore installations. In the future it may become necessary to make offshore structures more robust to deal with future climate change. However, as many aspects of future climate changes are uncertain (for example wave heights) this will make the design of some engineering parameters difficult. Scour protection could be required for foundations and cable arrays to compensate for possible increases in current stress on the seabed.

To derive extreme wave, water and wind levels, detailed records of past oceanographic conditions are required illustrating the need for continued collection of high quality metocean data. The collection of further records in areas presently not covered should also be implemented to ensure a good spatial coverage of historical oceanographic data. This could be targeted specifically in areas where large changes are expected.

Coastal structures

Coastal erosion

Currently the UK is estimated to have 3000 km of eroding coastline and around 2300 km of artificially protected coast, the longest in Europe (Eurosion, 2004). Increases in sea levels along with changes in the wave regime are likely to lead to increased coastal erosion. A response to these threats, where retreat is not feasible or economically viable could be an increase in the construction and the upgrading of coastal defences. Coastal defence construction can either be a hard defence such as groynes or walls or soft defence such as beach recharge or re-nourishment. An impact of sea level rise and changes to the wave regime will be an increase in demand for aggregates and timber for construction. In terms of soft defences, there is a possibility that beach recharge and re-nourishment may become less sustainable with an increase in the volume of sediment required to maintain beach levels.

Various natural defences present in the intertidal region (including saltmarsh, mudflat and sandflat) tend to dissipate wave energy thereby reducing the impact of waves on any defences behind. Any loss of intertidal area due to climate change would result in increased stresses on coastal defences.

Coastal defences are generally present in the UK where there are higher population densities and susceptible coastal geomorphology. The areas under greatest risk identified in the Foresight report are those around major estuaries and the east coast. The coastal processes that need to be considered in light of climate change are diverse and include changes to the frequency and duration of extremes tides, and tidal surges, waves, sediment transport patterns/pathways and any flows associated with freshwater inputs.

The main parameters defined in the UKCP09 report are sea level, waves and storm surges. In terms of increases in significant wave height and sea level rise impacts will be greatest in the southern regions and increases in storm surges are likely to be most significant in the Bristol Channel and Severn Estuary.

Coastal flooding

The impacts of changing sea levels and storminess in the future on existing structures has been assessed (Burgess and Townend, 2004 and Townend and Burgess, 2004). A number of key findings were made:

- The performance of coastal structures in depth limited conditions is very sensitive to even modest changes in water depth allowing larger waves to reach the structure.
- While there is a focus upon raising crest levels to accommodate sea level rise, we shall often need to re-engineer the whole structure due to increased scour around the toe of the structure.
- The increase in costs will usually be substantial.
- The increase in cost is likely to be two to four times the present cost to provide a similar level of performance.

The critical coastal processes are similar to those in coastal erosion and therefore geographically the greatest risk areas will be the same. This sector is concerned with the long-term (next century) as some structures have very long design lives due to their relatively high construction costs.

High Value Assets

A number of high value assets are situated within the coastal zone including:

- Ports (discussed in the shipping chapter)
- Nuclear power stations and waste depository
- Transport infrastructure
- Sewage works

Most of these assets will already be protected against coastal flooding and erosion and the as discussed in the sub sections above these pressures are likely to continue and increase into the future as a result of climate change.

Due to the relative permanent nature of these structures the obligation to continue to defend will extend into the future. This is especially true for nuclear developments which have a lifetime extending into centuries post decommissioning. It may be possible to re-site transport infrastructure but this could be costly and the feasibility will vary on a site to site basis.

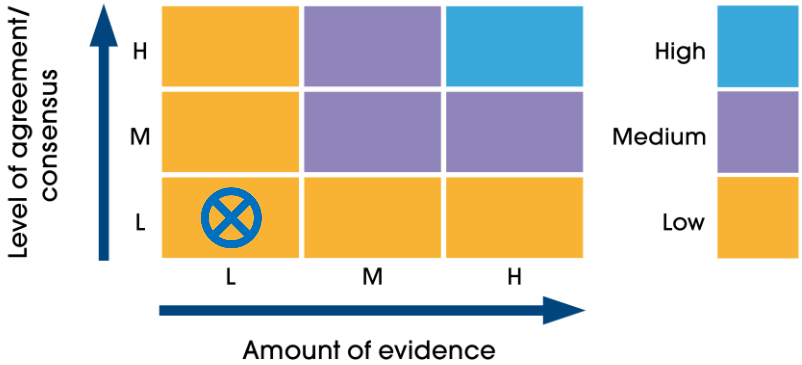
Because of this the location of any new assets in the future should be considered in the context of a sound understanding of long-term coastal evolution and geomorphology. As many projections of climate change focus on a timescale extending to 2100, and because structures are designed beyond this time period, robustness of design will be uncertain.

Design parameters

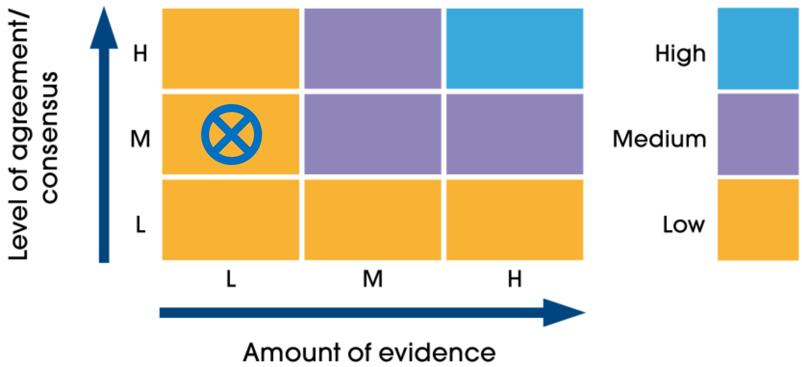
Coastal defences and structures being constructed at the present time allow for climate change within the design through guidelines issued by Defra (2006).

3. Confidence in the science

What is already happening: **Low**



What could happen: **Low**



There is a general lack of data throughout entire sector on both past and future impacts. Coastal impacts are generally better researched and understood than offshore impacts. This could be due to the relatively shorter life cycles of offshore structures compared to coastal structures.

4. Knowledge gaps

The top priority knowledge gaps that need to be addressed in the short term to provide better advice to be given to policy makers are:

1. Impacts of climate change on sediment transport processes and morphology. For example it would be useful to relate the UKCP09 outputs to sediment transport and morphological processes.
2. Lack of long-term records with which to assess past trends in oceanographic processes.
3. More information on changes to wave period as well as wave height would be beneficial in identifying future impacts on structures in the marine environment.

5. Socio-economic impacts

Offshore structures

The expected life of an offshore structure is currently around 20 years (Rees, 2008), the lifespan of offshore installations is also dependant on the reserves of fossil fuels in UK waters. Increased stresses on offshore structures will increase the cost of retrieving fossil fuels and generating renewable energy, the potential cost increase has not been quantified in the available literature.

Coastal Structures

It has been calculated that in terms of economic losses in the future the potential effects of coastal erosion on its own are minor compared to flooding and represent only 2-6% of total potential losses (Halcrow, 2001; Hall *et al.*, 2006). However, coastal erosion in the context of other coastal issues and the viability of property and infrastructure on eroding coastlines still merits serious attention (Hall *et al.,* 2006).

Figures are only available for both river and coastal combined and are not available exclusively for the coastal zone. Currently, flood and coastal defences cost approximately £464 million within the UK (Foresight, 2004). Engineering to address future flood risk could amount to between £22 and £75 billion by the 2080s depending on the scenario. As an example, in 20 years time the annual cost of flood and coastal defences would need to be between £700 million and £1.1 billion per year (Defra, 2004a). It is important to remember that the above costs are for flooding on both rivers and the coast.

An assessment of coastal erosion defence costs was undertaken by Defra (2004b) and showed that the cost of maintaining all defences at the current standard regardless of the benefit cost amounted £2.9 billion over the next 100 years at present value. Areas under the greatest threat from future erosion will be along major estuaries and the east coast (Foresight, 2004). Present levels of expenditure on coastal defence will not keep pace with future coastal erosion resulting in approximately one third of coastal defences being destroyed in the coming decades (Foresight, 2004).

Although it is useful to consider the financial costs of maintaining coastal structures it is important to also think about the social costs of protecting or not protecting communities. Government expenditure will by necessity be directed towards areas of greatest economic benefit (i.e. larger urban areas) leaving smaller communities more vulnerable to coastal change. It is likely that greater focus on management of future change through the land use planning system and other mechanisms as well as the maintenance of traditional defences may be necessary to effectively manage risk and social impacts on coastal communities.

This also relates to the identification of areas most susceptible to the impacts of climate change where the regions of greatest physical change may not necessarily coincide with regions of greatest social impact.

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