MOTT MACDONALD

Tidal barrier opens up a brighter future for Boston

In partnership with Environment Agency

Project
Boston Barrier

Location
Boston, Lincolnshire, UK

Client
Environment Agency

Expertise
Project management, outline and detailed design, environmental impact assessment, hydraulic modelling, stakeholder engagement

A new state-of-the-art barrier will better protect Boston from tidal flooding for the next 100 years. During its design and construction, our engineers demonstrated how sustainability and social outcomes can be embedded into all aspects of a civil engineering project.

The night the floods came

Few things in life can be more distressing than to see your home flooded and furniture and belongings destroyed.

Just ask the residents of Boston. On the night of 5 December 2013, the Lincolnshire market town was inundated by a tidal surge that overtopped defences along The Haven, the tidal river that connects the town's port to the sea. More than 50 streets were flooded, causing widespread damage to 800 homes and businesses.

Hundreds of people were forced to leave their homes. A few households became trapped by the floodwaters and had to be taken to safety by rescue teams with inflatable boats. It would take months for the community to fully recover. Only half of the residents whose properties were flooded were covered by insurance. A year later some of them were still living in temporary accommodation.

Boston, which lies entirely within a flood plain, has a long history of tidal flooding. Previous flood events in 1953 and 1978 had highlighted the need for improved defences against tidal surges. A tidal barrier was identified as the best solution, not just to reduce the risk of tidal flooding but to enable opportunities for regenerating the town and its waterways.

After the floods of 2013, the construction of a tidal barrier was given national priority status by the Environment Agency.

BMMJV, a joint venture company formed by Mott MacDonald and BAM Nuttall, was awarded the contract to deliver this critical piece of infrastructure. For both the scheme's outline and detailed design, Mott MacDonald's engineers and specialists provided project management and civil, structural, geotechnical and mechanical and electrical design services.

The aftermath of the flooding in one of Boston's residential streets.

Credit: Environment Agency

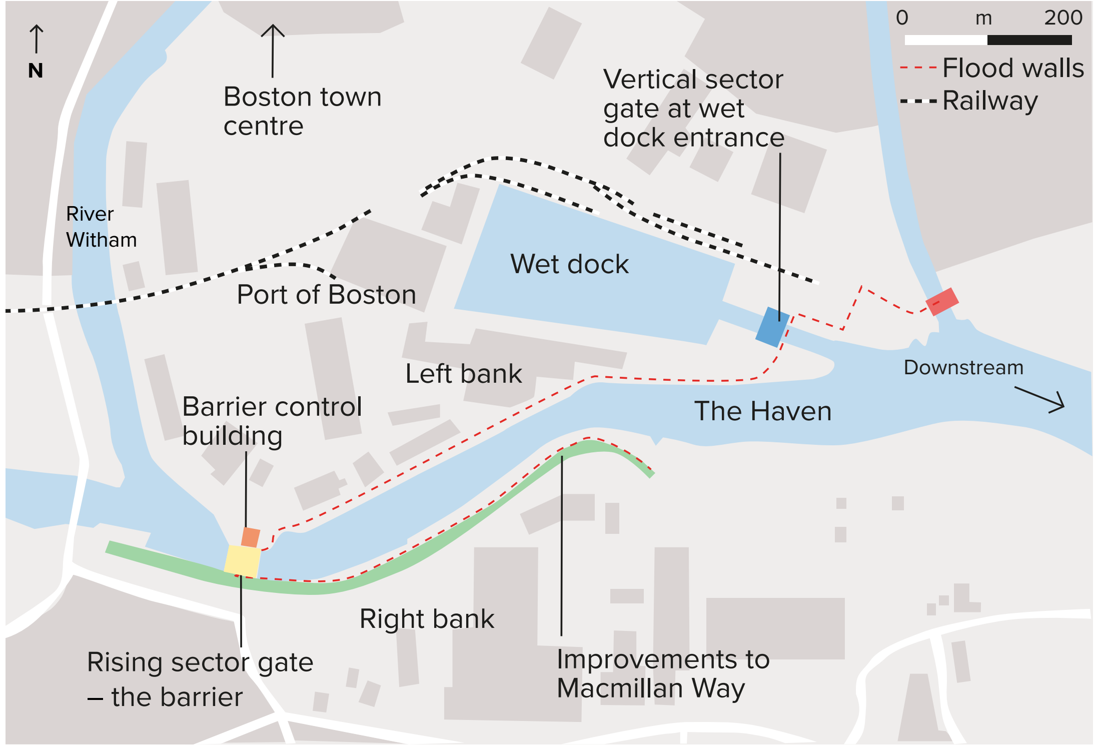
Front cover image credit: Environment Agency

The project delivery team

Environment Agency – commissioning authority
A public body sponsored by the Department for Environment, Food & Rural Affairs. Within England, its responsibilities include managing the risk of flooding from rivers, reservoirs, estuaries and the sea.

Mott MacDonald – lead architect and consultant
A 17,000-strong employee-owned global engineering, management and development consultancy. It plans, designs and advises on the delivery, operation and care of social and economic infrastructure across all sectors.

BAM Nuttall – lead contractor
Part of the Royal BAM Group, one of Europe's largest construction companies, employing 20,000 people and with a strong heritage in maritime and coastal projects.



A map of Boston illustrating the location of the rising sector gate and other elements of the scheme.

Project milestones

Dec 2013
Tidal surge floods 800 homes and businesses in Boston

Dec 2014
Barrier announced as a UK government national priority project

Oct 2016
Funding approved by UK Treasury

Apr 2017
Four-week public inquiry begins

Dec 2017
Project given green light by government

Innovative solutions cut costs and carbon

An aerial view of the construction site as the rising sector gate is unloaded from the barge that transported it from the Netherlands.

The barrier is a rising sector gate, sitting across The Haven to the south of central Boston, which can be raised to protect the town against a tidal surge in just 20 minutes.

In the event of a predicted tidal storm surge, the steel gate – 28m wide, 11.5m high and weighing 362t (unballasted) – will be rotated into position by two 55t hydraulic rams, among the biggest and most powerful ever installed in the UK.

In normal conditions, to allow boats to pass safely above it, the gate lies flush with the riverbed within a recess on the floor of the barrier's reinforced concrete housing – a 'trough' measuring 35m long, 35m across, and with 12m high walls which are up to 5m thick in places. Anchorages for the hydraulic rams and the pivots for the gate are cast into the walls. The structure was constructed entirely within a steel sheet pile cofferdam to create a dry work site within the tidal river.

Charlie Bell, project manager for Mott MacDonald, says: "We engineered the design of the gate structure, its operating machinery and control building, bringing our geotechnical, civil and structural engineering capabilities to bear. We identified significant cost savings, while our innovative solutions designed out all piles under the barrier and made practical and effective use of low-carbon concrete, reducing the project's carbon footprint."

The revised piling system, combined with efficient temporary works design, reduced the requirement for 1500t of steel, saving 2190t of embodied carbon.

Jan 2018

Work begins on site

Jan 2019

Barrier cofferdam is completed

20

minutes to raise the barrier gate

3796t

of embodied carbon saved across project

The rising sector gate shortly after installation.

The barrier structure that forms the housing for the gate is made up of more than 6000m^3 of concrete and 862t of reinforcement.

Producing cement is energy and carbon intensive. The concrete mix for the structure incorporates 70% ground-granulated blast furnace slag (GGBFS), a by-product of the iron industry, as a cement replacement. This saved a total of 1246t of carbon. GGBFS also has properties that are suited to the aggressive marine environment: getting the concrete mix right was key to meeting the barrier's 100-year designed working life.

Amber Telford, Mott MacDonald's global practice leader for water-retaining structures, says: "As with any bespoke civil engineering project, the concrete formulation is fundamental to ensuring sufficient durability for the design life. A variety of concrete mixes were tested and, considering environmental exposure and the chemical composition of the soil, groundwater and river water, a process of elimination ensued to establish the final mix design."

Limestone was used as the coarse aggregate in the mix. This is the preferred choice for water-retaining concrete as it minimises the co-efficient of thermal expansion. This lowers the reinforcement requirements to control cracking during construction. And because of its high compressive strength, the limestone aggregate will also reduce the potential for cracking over the working life of the barrier.

Meticulous structural design produced a highly efficient steel reinforcement design. Rebar cages were prefabricated and delivered to site as modules, which shaved seven weeks off the programme's critical path.

Feb 2019
First concrete poured in base of barrier

Oct 2019
Hydraulic rams installed and structural concrete work completed

Nov 2019
Primary barrier gate arrives from the Netherlands by barge

Concreting to the stilling basin. This part of the structure's base is where water falls when the gate is partially raised and is designed to dissipate the water energy before it flows downstream.

862t
of steel reinforcement

6000m^3
of concrete poured

The use of precast concrete beams for the gate recess, pictured here in the factory soon after casting, saved materials and carbon during construction.

16,000l

of Panolin biodegradable oil contained in gate operating system

The concave recess on the concrete floor of the barrier structure, which houses the gate when not in use, was formed using 24 curved concrete elements that were precast off site.

To cast the shape in situ would have required complex bespoke temporary formwork. Using design for manufacture and assembly (DfMA) simplified construction, saved costs and carbon, achieved higher quality, and removed a potentially risky activity from the programme.

“

I’m really proud of how everybody worked together

On the night of 5 December 2013 I was the flood incident duty officer in our Boston control room. As the storm surge came down the North Sea, we issued flood warnings, closed all the flood gates, and evacuated our people from the coast. But once the defences were overtopped, there was little more we could do.

The main aim of the barrier is to improve tidal flood protection, but we also wanted the project to generate wider benefits. We boosted the town’s economy by millions of pounds by sourcing suppliers and materials locally. We visited local schools to promote STEM (science, technology, engineering and maths) subjects and civil engineering as a career. The United Nations Sustainable Development Goals helped us to think of ways we could further enhance the community and environment we were working within.

The project team was made up of different organisations and I’m really proud of how everybody worked together. It didn’t matter whether you were paid by the Environment Agency, Mott MacDonald or BAM Nuttall, we were one team. We shared offices and developed open, collaborative relationships. We were all focused on delivering the barrier for the people of Boston.

Adam Robinson
Project director – Boston Barrier, Environment Agency

Murals on the new right bank floodwall reflect the town’s maritime history and were developed in consultation with the local community.

Credit: Environment Agency

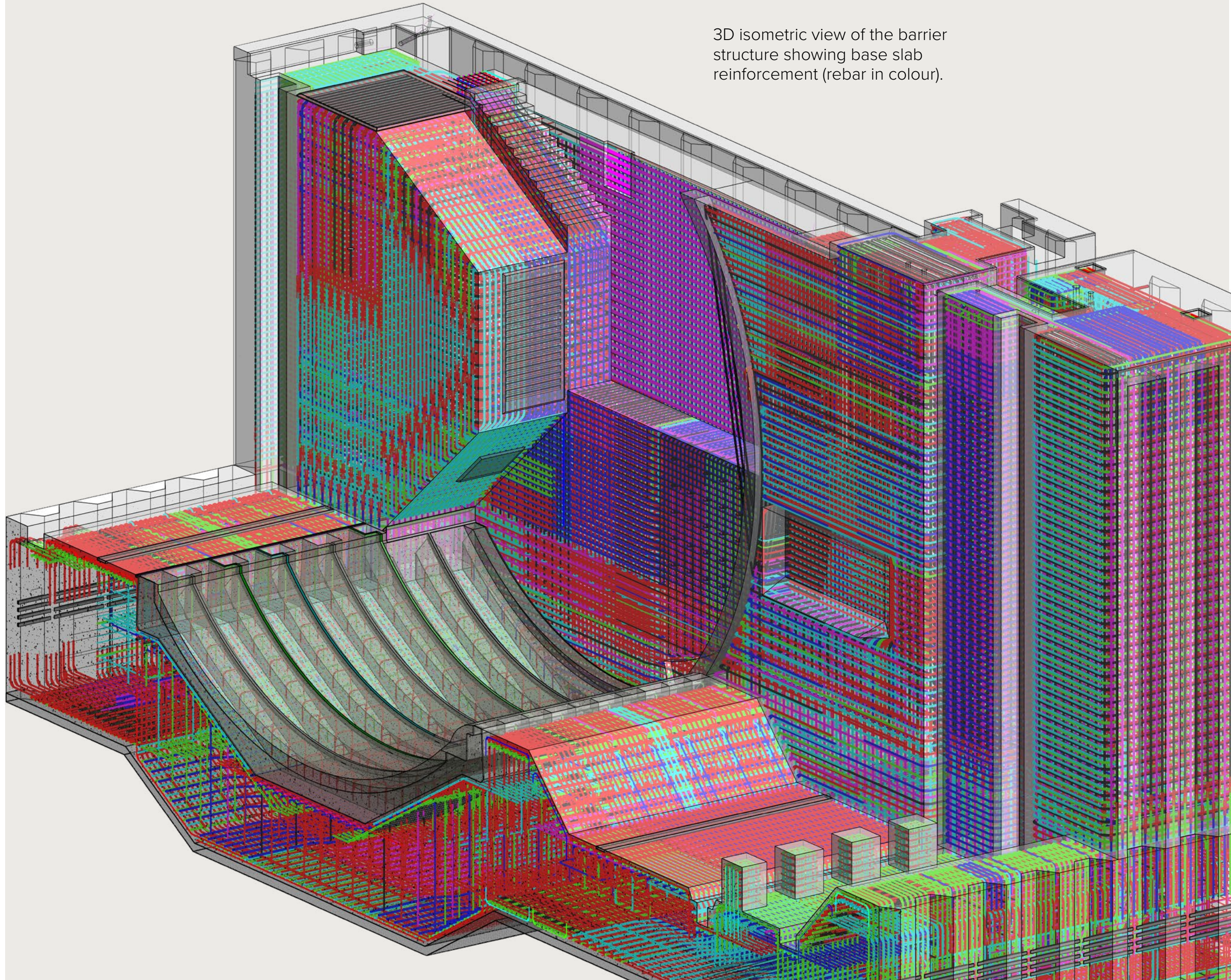
Digital approach to delivery

Digital delivery has been at the heart of the project from the outset and the team's guiding principle has been: 'Build it twice – once virtually, once for real'.

BIM (building information modelling), incorporating 3D modelling tools, was used throughout the project. It enabled virtual construction rehearsals, minimising risks and improving on-site safety. BIM provided a common data environment (CDE) which improved communication across the project team and between suppliers, allowing users from different organisations to work on the same models at the same time.

There was just one set of project information, avoiding the problem of version control, which is a common bugbear on projects that do not work in a CDE. Digital collaboration enabled the team to optimise the design of structures and the integration of temporary and permanent works, saving time and money, cutting waste and material requirements, and reducing environmental impacts.

Visualisations produced by the project team, including virtual reality animations, proved to be very effective communication aids when used to show stakeholders and local people what the barrier would look like.



3D isometric view of the barrier structure showing base slab reinforcement (rebar in colour).

A closer view of the anchorages for the hydraulic ram and pivot on the right bank side as the gate nears the closed position during a post-installation test.

362t

weight of primary barrier gate

700t

ballasted weight of primary barrier gate

Dec 2020

Primary barrier gate installed

Mar 2020

Barrier testing completed

The barrier is designed to withstand a large number of load combinations. In use it will mainly hold back high tides: in the event of a tidal surge flood, when the gate is closed, the axial compression will be 19.5MN at the gate pivot. In the future the gate could be used to impound water upstream and the anchorage would be placed in tension.

The barrier must also cope with temporary rotational loadings including those imposed when the gate is opened and closed, or raised for inspection and maintenance – or potentially shock loading from accidental vessel impact.

Loads are transferred into the reinforced concrete side walls of the barrier structure through large post-tensioned anchorages. It was essential to model loading accurately to understand its distribution through the structure, ensuring the required structural muscle was provided in the right places while keeping the design efficient.

“For forces of this magnitude, a bespoke solution was developed using best practice from the bridge and offshore industries,” explains Mott MacDonald’s Ashwin Rego, the project’s structural lead.

“The holding down (HD) bolts were post-tensioned to 2.6MN at lock-off. To increase the shear resistance, an arrangement of steel strips was welded to the underside of the anchorage base plates that interlock with ridges on the concrete surface. Grout applied before the bolts were tensioned provided a completely solid connection.

“Dense and complex reinforcement was required around the HD bolt assembly. It could have resulted in buildability challenges, but we resolved them through great collaboration within the project team, using BIM to find the right configuration.”

£110M
project cost

£1.16bn
economic benefits

It is critical the infrastructure to operate the barrier is flood-resilient in case part of the defences fail and are overtopped.

Under the original design, the gate's operating machinery would have been placed on the ground floor of the control building. This would have required waterproofing the building and, in turn, designing its piled foundation to provide restraint against floatation in the event of flooding.

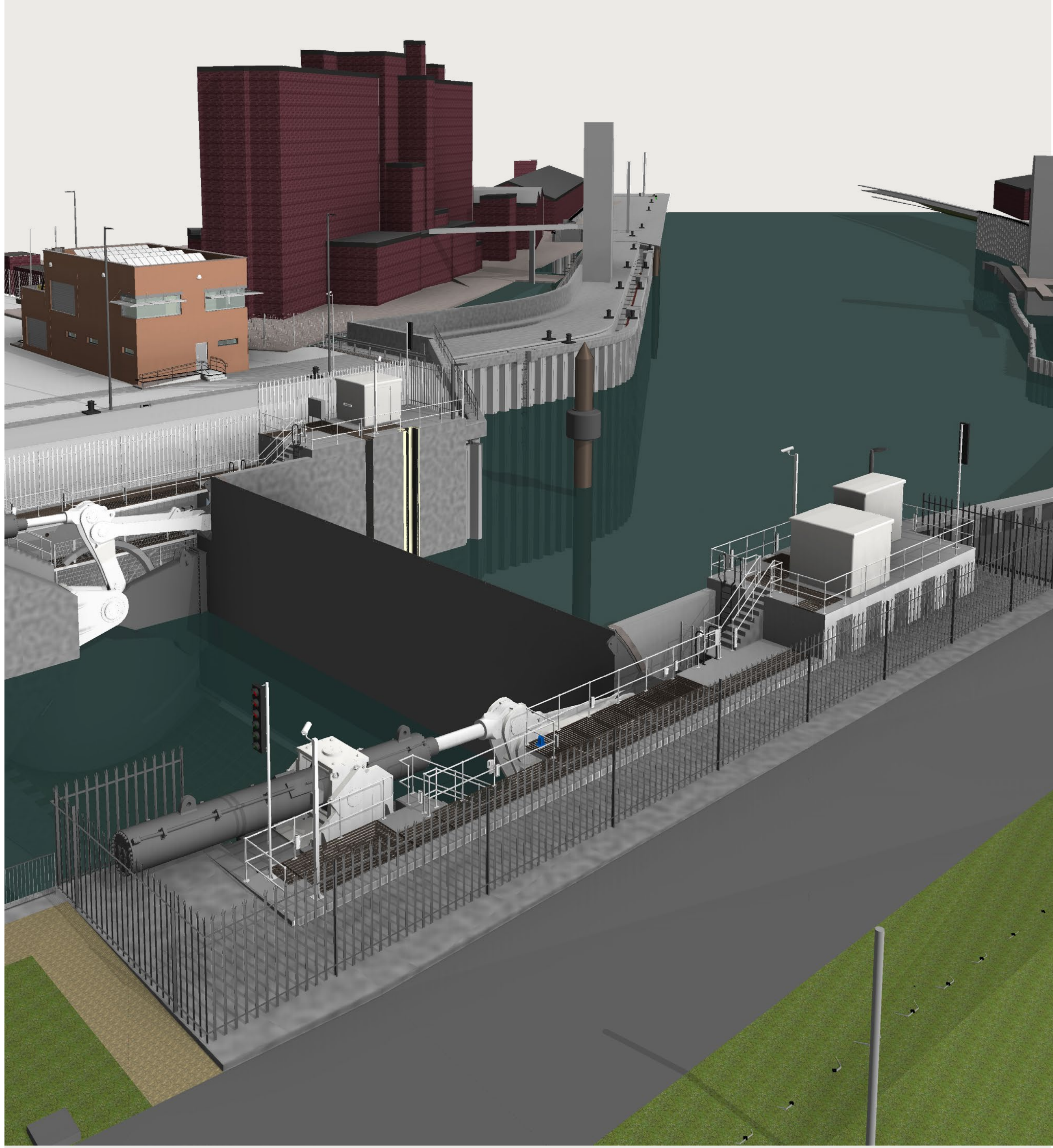
Using BIM, the project team showed that inverting the design of the control room to position all essential plant on the first floor achieved the required level of operational resilience against flooding without needing to waterproof the entire structure.

The control building is located on reclaimed or 'made' ground. This can sometimes pose problems if the fill used lacks compressive strength or if it is poorly compacted.

However, the site investigation suggested that the made ground was strong enough for the building to be constructed on a shallow raft foundation, which was confirmed by a settlement load test on site.

This removed the requirement for piled foundations to provide resistance against uplift and enabled the removal of 70 piles from the design, saving £300,000 in materials and 360t of embodied carbon, as well as four weeks of construction time and three weeks on the design programme.

The ability to visualise the effect of design changes in BIM also enabled the design team to locate the control building closer to the river, improving operators' view of the barrier, and to optimise the layout for health, safety and wellbeing.



BIM render of how the completed barrier and control building would look on completion – and looks now.

The economic benefits of the barrier are significant

A community hub was opened near the barrier to support outreach projects as part of consultation and engagement activities.

Credit: Environment Agency

The night Boston was flooded coincided with the news that Nelson Mandela had died, so the devastating impacts on the town didn't come under the national spotlight like other flood events.

But for the people who saw the water gushing over walls and into their homes, those dramatic images will never leave them. In the aftermath, Boston's community spirit shone through as everybody rallied round to help each other.

There had been discussions for some time about the need for a tidal barrier. After the flood, it was a case of: 'There's been enough talking, we need to do something now.'

We hardly had any complaints during the barrier's construction. Given the size of the scheme and its location in an urban area close to people's houses, that's a measure of how well the project was managed and how well the community was engaged and consulted.

The economic benefits of the barrier are significant for the town's regeneration. The resilience and protection it provides will enable local businesses to stay in the town and grow, while also attracting new businesses. It's the same with housing.

The barrier, a tremendous engineering feat, will raise Boston's profile, which is good for the visitor economy, and change how the town is viewed nationally, which will boost civic pride as well as inward investment.

Michelle Sacks
Deputy chief executive, Boston Borough Council

Protecting Boston against climate change

Construction work started in January 2018 and the gate was installed in December 2019.

Progress was slowed, but not stopped, by the COVID-19 pandemic. Given Category A status by the Environment Agency, the project was allowed to continue, albeit subject to restrictions. Social distancing and working bubbles were observed by the workforce on site, visitors were not allowed, and the whole of the design team worked remotely from home.

The Boston Barrier became fully operational in December 2020. When the whole scheme is completed, there will be new flood defence walls on both banks, and new vertical sector gates – 18m wide and 11.5m high – across the entrance to the Port of Boston's wet dock.

These gates will better protect the port's facilities as well as homes and businesses downstream of the barrier.

All this infrastructure will provide the town with protection against a 1 in 300-year flood event, accounting for future sea level rise and the likely increased frequency of tidal surges as a result of climate change. It would have prevented the flooding of December 2013.

When all works are completed in 2023, more than 14,000 homes and 800 businesses will be protected, including 226 listed buildings, the most famous of which is the 'Boston Stump', the medieval St Botolph's Church with its iconic tower. A landmark for over 500 years, the 2013 flood caused almost £1M worth of damage to the building.

A drone image of the construction site taken during installation of the rising sector gate.

800
businesses protected from tidal flooding

14,000
homes protected from tidal flooding

Mar 2020
Coronavirus restrictions introduced

May 2020
Cofferdam removed

Jun 2020
Barrier channel open to river traffic

Dec 2020
Primary barrier gate fully operational and handed over to Environment Agency

Jun 2021
New dock gates for Port of Boston arrive by barge

The difference in water levels between the two sides of the barrier when it was first used operationally.

Credit: Environment Agency

100 years

designed working life of barrier

1 in 300 year

flood event protection

Nov 2021

After a high tide warning, the barrier is raised for a potential flood event for the first time

The barrier is tested monthly to ensure it will always be ready to be raised in the event of a severe storm or tidal surge.

In the early hours of 7 November 2021, after a high tide warning, the barrier was used for the first time to protect the residents and properties in the town. Although the peak high tide water level came in below forecast levels, there was still a difference of 3.7m between the barrier's upstream and downstream water levels. Data recorded from the event will be used to further improve its use in the future.

Project director Adam Robinson says: "This was the first time the barrier – and the team operating it – had been brought into action against the real threat of flooding and we were prepared and ready. A truly momentous moment for Boston and everyone who has worked on the scheme, coming just two years to the week after the primary gate was delivered and installed."

An aerial view of Boston showing St Botolph's Church.

> # Barrier is helping to regenerate the town

When I was elected in 2015, I was very conscious that people in Boston were still living with the consequences of the flooding that happened 18 months before. My father-in-law was a science teacher at Boston Grammar School at the time and his lab was completely destroyed. It shows how devastating the impacts of flooding can be, even affecting the outcomes of children's education.

This constituency is the most at risk of flooding in the UK because much of the area is below sea level. The growing risk of climate change comes on top of that. Even so, when I lobbied for the barrier to be built, I remember the government questioning whether it was a good idea or not.

Now it's built, the barrier is making it easier for businesses to obtain the insurance they need to be able to grow. It is helping to regenerate the town and region by accelerating investment. Residents feel safer in their homes.

The Boston Barrier demonstrates how big infrastructure projects, if you get them right, can bring wider benefits that are good for the economy, the environment and communities.

Matt Warman
Member of Parliament
for Boston and Skegness

Delivering positive social outcomes

The scheme has delivered far more than better flood defences and increased climate resilience.

It is estimated that the project's economic benefits to the area are worth in excess of £1bn. The project team developed a methodology which used the United Nations Sustainable Development Goals (SDGs) as a framework to analyse how the scheme could also provide wider societal and environmental benefits.

Mott MacDonald civil engineer Kaye Pollard says: "Our team have used the SDGs as a basis for monitoring and evaluating success, incorporating them where it would help improve the project. This has maximised the project's benefits by supporting and ensuring great outcomes for the Boston community."

Emma Howard-Boyd, chair of the Environment Agency, commented: "The Boston Barrier was the first major construction project undertaken by the Environment Agency where we mapped work against the UN's Sustainable Development Goals. The learning from this will help us, and others all over the world, to steer large and small infrastructure projects so they are producing multiple societal and economic benefits that go far beyond their stated purpose."

The barrier has delivered benefits against all 17 Sustainable Development Goals, exemplifying how sustainability and social outcomes can be embedded into all aspects of a civil engineering project (see following pages).

2022/2023

New gates installed at Port of Boston's wet dock entrance and flood defence walls on both banks finished, marking the project's completion

The barrier, pictured here in the open position, will bring wider social and economic benefits in addition to increased flood protection.

Credit: Environment Agency

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The barrier is not only setting a new benchmark for flood defence construction with its innovative design, construction and implementation, but is a true demonstration of how the impact of a natural disaster can be assessed and responded to in a way that transforms an entire community.

State of the Nation 2021
Institution of Civil Engineers

SDG 1 – No poverty

Boston has some of the most deprived neighbourhoods in the UK, meaning people living there are less resilient to the impacts of flooding. Post-flooding surveys in Boston in 2013 found that 99% of respondents did not have contents insurance. The Boston Barrier will better protect these communities.

SDG 2 – Zero hunger

The region is a major source of food production and distribution for the UK. More than 1700ha of agricultural land around Boston was inundated during the December 2013 flood event. Better flood protection of this valuable arable land will help improve the nation's food security.

SDG 3 – Good health and wellbeing

The scheme gives tidal flood protection to Pilgrim Hospital, which provides major specialist treatment and 24-hour major accident and emergency services to the whole of south and south-east Lincolnshire.

SDG 4 – Quality education

The contractor gave apprenticeships to six young people, providing them with technical skills and employment opportunities, and created return to-work opportunities for people who have been out of work for several years. The Environment Agency engagement team worked with local schools and colleges to educate students on flood risk and promote engineering as a career.

SDG 5 – Gender equality

There was a good gender mix within the project delivery team; 41% of the design team were women, which was unusually high for the industry. The project was part of the Women into Construction scheme.

SDG 6 – Clean water and sanitation

Flood risk reduction will limit the number of unplanned sewage overflows as a result of extreme weather, reducing pollution into river and marine systems. Marine-safe hydraulic oil was used in the hydraulic cylinders controlling the rising sector gate.

SDG 7 – Affordable and clean energy

Photovoltaic panels were installed on the roof of the barrier control building, providing a 9.6kW renewable power supply. An air-source heat pump further reduced the building's carbon footprint.

SDG 8 – Decent work and economic growth

The barrier will contribute to economic regeneration by giving the private sector confidence to invest in the development of the town's riverside environment and the region's waterways, boosting tourism and improving connectivity between towns in the east of England. These economic benefits are estimated to be worth in excess of £1bn. More than £8M was spent on construction materials and services within 80km of the site, supporting local businesses.

SDG 9 – Industry, innovation and infrastructure

The project provides significant tidal flood protection to local infrastructure assets, including the A16 trunk road (which is also a vital emergency evacuation route), the railway line between Boston and Skegness, the Port of Boston, and the local electricity substation.

SDG 10 – Reduced inequalities

Boston has a high proportion of residents born in the EU or accession countries. To be as inclusive as possible, community engagement campaigns were multilingual and run on several platforms. Translators were available at public drop-in sessions, which were run from 12pm to 7pm to allow access for those with differing working patterns.

SDG 11 – Sustainable cities and communities

Public spaces were enhanced as part of the project. These include improvements to the Macmillan Way, a long-distance walking trail along the right bank of The Haven, to make it wheelchair accessible. Floodwalls were decorated with motifs reflecting Boston's maritime history, an idea developed based on feedback from the local community.

SDG 12 – Responsible consumption and production

The project has reduced waste generation through prevention, reduction, recycling and reuse where possible. Examples include: reuse of dredged material as backfill and capping at a local landfill site, avoiding the need for 30,000 lorry movements; collaboration with a concrete supplier to reduce the cement content of the actual supplied mix while still ensuring it met strength requirements; and maximising the use of prefabricated elements in construction, which reduced waste materials produced on site.

SDG 13 – Climate action
Climate change causes sea level rise and increases the risk of extreme weather events, increasing the risk of tidal surges at Boston. The barrier prevents surges inundating the town and strengthens the flood resilience of the community.

SDG 14 – Life below water
Findings from our environmental impact assessment influenced the barrier's design to ensure there were no significant adverse impacts, including to the Wash, the largest estuarine system in the UK and a site of special scientific interest.

SDG 15 – Life on land
Tidal flood protection prevents permanent change to or impacts on freshwater ecological features and habitats due to regular sea water intrusion. The project team introduced a terrestrial plant population of nationally rare Boston horsetail along the Macmillan Way.

SDG 16 – Peace, justice and strong institutions
From the project's outset, extensive consultation has taken place with the local community and river users to avoid any unintended negative impacts. A community hub was provided on site to allow direct access to the project team every week for community outreach projects.

The project's BIM model was used to develop virtual navigation simulations for river users.

Credit: Environment Agency

SDG 17 – Partnerships for the goals
Collaborating with the Port of Boston, the project team used a ship simulation centre to create a virtual navigation simulation which included leisure craft, enabling river users to pilot their vessels virtually. This helped the whole river community to understand the future navigation changes and allowed collaborative discussions between stakeholders, which directly influenced the navigation management plan.

Charlie Bell, Mott MacDonald, centre left, and Adam Robinson, Environment Agency, centre right, being presented with the Climate Resilience Project of the Year at the 2021 BCIA Awards.

Credit: © Paparazzi VIP Photography

Mott MacDonald's Amber Telford, third from left, Phil Jones, senior structural engineer, fourth from left, and Ashwin Rego, fifth from left, pictured at The Concrete Society Awards 2021.

Credit: © Simply Photography

An award-winning project

RICS Social Impact Awards 2020, East Midlands
Winner: Infrastructure category

ICE Awards 2020
Edmund Hambly Medal for substantial contribution to sustainable development

ICE East Midlands Merit Awards 2020
Team Achievement Award

ICE East Midlands Merit Awards 2021
Large Project of the Year
Sustainability Award

Flood and Coast Awards 2021
Digital Excellence

British Construction Industry Awards 2021
Climate Resilience Project of the Year

APM Project Management Awards 2021
Engineering, Construction and Infrastructure Project of the Year

The Concrete Society Awards 2021
Highly commended

Opening opportunities with connected thinking.