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Raising the standard of flood protection in Hull: the Humber Hull Frontages flood defence scheme

Relever le niveau de protection contre les inondations à Hull: le projet de défense contre les inondations des Humber Hull Frontages

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ABSTRACT: The Humber Hull Frontages flood defence scheme reduced the risk of flooding from the Humber estuary for 113,000 properties and it consists of more than seven kilometres of tidal flood defences along the estuary frontage. This paper describes the design of a variety of flood defences in challenging ground conditions, typically comprising deep fill deposits associated with the pre-existing flood defences and with large areas of reclaimed land overlying normally consolidated soft tidal flat deposits. The solutions provided to overcome multiple design and construction constraints due to the current and historical use of the project setting are presented in this paper.

RÉSUMÉ: Le projet de défense contre les inondations des Humber Hull Frontages a réduit le risque d'inondation par l'estuaire de l'Humber pour 113,000 propriétés et il comprend plus de sept kilomètres de défenses contre les inondations maritimes le long du front de mer. Ce document décrit la conception de diverses défenses contre les inondations dans des conditions de sol difficiles, comprenant généralement des dépôts de remblai profonds associés aux défenses contre les inondations préexistantes et de grandes zones de terres récupérées recouvrant des sols alluviaux mous normalement consolidés. Les solutions apportées pour surmonter les multiples contraintes de conception et de construction dues à l'utilisation actuelle et historique du cadre du projet sont présentées dans ce document.

Keywords: Flood defence; soft soil; sheet piles; seepage.

1 INTRODUCTION

The city of Hull lies on the north bank of the Humber Estuary and is protected from tidal flooding by the River Hull Barrier and a combination of raised defences of varying age, condition and height along the Humber Estuary frontage. The objective of the Humber Hull Frontages (HHF) project was to improve the existing tidal flood defences so that they would provide a flood defence for 2040 tidal flood event levels with provision to install future additional defences for 2115 tidal flood event levels.

The £42 million scheme reduced the risk of flooding for 113,000 properties upgrading more than seven kilometres of tidal flood defences, from St Andrew's Quay Retail Park in the west to Victoria Dock Village in the east, as shown in Figure 1.

A wide range of defences were proposed for the scheme, ranging from installation of driven piles, construction of new piled or gravity walls, raising of the existing flood defences and improvement of the existing flood defences.

Figure 1. Plan overview of the Humber Hull Frontages scheme.

This paper focuses on the works at Victoria Pier (Zone 6) and Victoria Dock Village East (Zone 8), where the challenges posed by both historical and current land use had the greatest impact on the design and construction of the flood defences.

2 GROUND CONDITIONS

Like many UK east coast estuaries, the geology of the superficial deposits along the Humber is complex. The wide range of environmental conditions and sea levels has resulted in the deposition of a varied and discontinuous sequence of glacial, fluvioglacial and tidal flat deposits (TFD) consisting of sands, gravels, silts and peats.

A conceptual ground model of the River Hull Barrier, which is also applicable to the HHF project, is depicted in Figure 2.

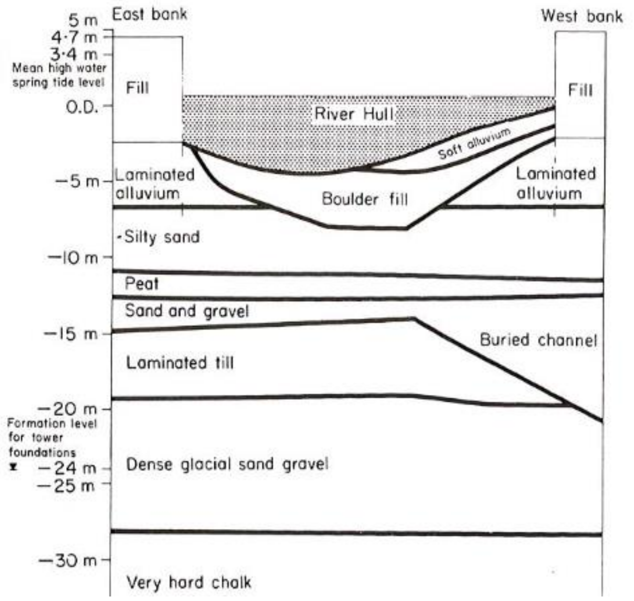

Figure 2. Conceptual ground model of the River Hull Barrier (Fleming et al., 1980).

In general, the ground conditions at the scheme comprise a variable thickness of made ground overlying TFD. Notably, along the Humber frontage vast areas have been reclaimed from the estuary through time and flood defences were built on top of the reclaimed land, resulting in the presence of sections of deep fill, mostly consisting of reworked TFD, overlying a starter layer of gravel to cobble sized chalk. Typically, a 1.0 to 1.5m thick firm to stiff desiccated crust is found at the top of the TFD, where this has not been removed by historical anthropogenic activities. The underlying TFD generally consists of normally consolidated low-strength and low-stiffness silty clay and clayey silt with organic content and peat layers.

The deeper geology comprises mostly glacial till overlying bedrock of the Burnham Chalk Formation from the Upper Cretaceous.

Groundwater associated with the chalk is sub-artesian, with a significant rise noted following the installation of deep boreholes. Groundwater in drift deposits is tidal and is also influenced by the pressure in the Chalk aquifer locally.

3 VICTORIA PIER

Victoria Pier, built in 1825, is a disused ferry terminus named after a Royal visit by Queen Victoria in 1854. The existing structure is a timber pier and jetty, with existing river walls consisting of tied sheet piles.

The new flood defences required complex piling works as the poor condition of the existing tied sheet pile wall indicated minimal residual life to support a new gravity flood wall constructed on the land.

Figure 3. Construction works at Victoria Pier.

Key features and challenges include the following:

- The existing timber pier required partial demolition to fit new sheet piles in front of it.
- The existing sheet piles along the upstream end of the quay wall were inclined at 6 degrees, so the new piles had to be raked to avoid a clash at depth.
- The rake of the new sheet piles had to avoid conflicting with the deep vertical timber piles to the pier.
- The quay wall at the mouth of the River Hull was vertical, so the new sheet-piled wall had to change inclination from raking to vertical. This was also necessary to avoid conflict with the vertical 'dolphin' pier to the footbridge.
- New sheet piles had to be installed within 2m of an existing structure, therefore a minimal vibration method was required to install piles.
- Presence of known (and unknown) buried obstructions.
- The ground conditions were highly variable and included very soft organic soils to 22m depth, a buried sand-filled channel and sub-artesian groundwater.
- The site was less than 100m from the location of a 1999 tunnel collapse (Grose et al 2005), which resulted in the largest claim (£50M) ever made under a Contractors 'all risk' policy.

- Working through the covid pandemic.

Clearly this was a site that required a comprehensive ground investigation and management of ground risk.

A schematic ground model of this area is shown in Figure 4. The SPTs did not exceed N10 until 22.5m depth in the central area, however adjacent CPT investigation indicated higher soil stiffness and it was likely that the high-water pressures caused piping at the base of the boreholes.

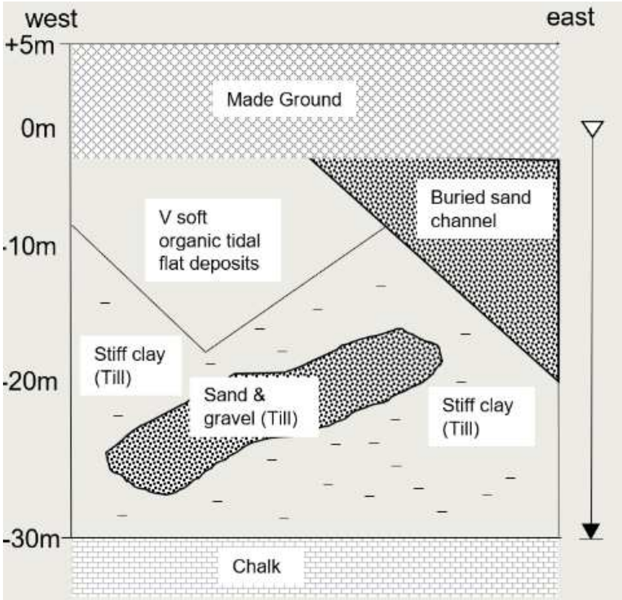

Figure 4. Schematic ground model at Victoria Pier.

Historical records indicated that there would be a high density of buried obstructions. To avoid the need for the installation of ties or anchors to support the sheet piles, the initial proposal was to carry out a wet soil mixing operation to the upper part of the passive wedge, working in 6x6x6m cubic zones during each 'window' of low tide.

Unfortunately, the time required for the regulatory approval process for mixing cement into the mud flats proved to be too long to fit into the programme and the scheme had to revert to an alternative solution. A tied wall was considered lower risk than an anchored wall as the ties could be threaded between and beneath existing timbers and services in open excavations.

Works commenced with the upstream piles, installed at a 3-degree rake 2m in front of the existing wall and 15m in length to avoid conflict with the exiting piles at depth. Although small, the rake on the sheet piles made the design of the wailing beam complex and a double UKB was needed to resist eccentric loading.

Figure 5. Installation of raked piles along the Humber.

As the wall turned the corner from the River Humber to the River Hull, a bespoke triangular pile was installed to transition to vertical piles along the River Hull face. This was vital to enable piles to be pressed rather than driven near existing buildings.

Figure 6. Installation of pressed piles along the River Hull.

As expected, the installation of anchor piles was complex. Some had to be pressed in proximity to a grade II listed toilet block, several were realigned due to obstructions with the tie roads being lengthened, and towards the upstream end of the works, several anchor piles refused at very short depths, potentially due to the original masonry quay wall, and were replaced with a balanced gravity RC wall constructed in open excavation to 3m depth.

4 VICTORIA DOCK VILLAGE EAST

The proposed flood defences at Victoria Village East consisted of a reinforced concrete flood wall up to 1.5m high running at the back of the gardens of the residential properties along the estuary.

The 1856 Ordnance Survey map of Hull shows that the High Water Spring Tide line at Victoria Dock Village East was about 150m to the north of the existing coastline. Land reclamation took place in the second half of the 1800s, consequently, a 7 to 8 metres thick layer of made ground was encountered.

The main challenge for the works in this area was represented by the historical use of the site.

Figure 7. Aerial photograph showing historical timber pond, slipways and shipbuilding yard.

Historical maps and pictures show the presence of the following features:

- a timber pond located to the east of the half tide and outer basins; this basin was then infilled and residential buildings were constructed over it.
- two slipways and a historical tidal dock were located within the area of the proposed works. This was confirmed by an obstruction and locally different ground conditions encountered during the investigation at the location of one of these slipways.
- the area east of Harbour Way used to be a shipbuilding yard, where ships were built on the groynes onto a basic slipway.

The main issue presented by these historical features was related to the potential for seepage paths existing underneath the new flood defences. While the typical infill used for reclaimed land in the area consisted of reworked TFD silty clay or clayey silt, hence with low permeability and low risk of seepage during flood events, the ground investigation confirmed that coarser soil was used to infill these features at a later date than the surrounding area.

Seepage analyses were carried out for the area, considering both the typical ground conditions and ground models specific to the infill recorded at the location of the buried historical features. The analyses showed that if a material with hydraulic conductivity greater than 10^{-5}m/s was encountered below the flood wall foundation level, seepage could have occurred below the walls. Sheet piles for seepage cut-off were therefore installed in the areas where the proposed flood walls encountered permeable infill.

5 CONCLUSIONS

The Humber Hull Frontages scheme provided a high standard of flood protection for 113,000 properties along the estuary of the Humber, in Hull. A wide range of geotechnical works were constructed for the scheme, the majority of which were successfully completed between 2019 and 2021, with the project being officially opened to the public in 2022.

The design and construction of the proposed works faced several challenges, mostly related to the constraints posed by the historical and existing urban context of the works and the onerous ground conditions, comprising a great thickness of made ground and soft TFD.

Two particularly challenging areas of the scheme were Victoria Pier, where the design of the new piled wall had to adapt to the presence of buried obstructions, existing sheet piles and listed structures, and Victoria Dock Village East, which historically was the site of features such as slipways and artificial basins.

A good understanding of the impact of these constraints on the proposed works and flexibility in the design approach, adapting to modifications required during construction, allowed the successful delivery of the scheme.

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