The paper was published in the proceedings of the 11th Australia New Zealand Conference on Geomechanics and was edited by Prof. Guillermo Narsilio, Prof. Arul Arulrajah and Prof. Jayantha Kodikara. The conference was held in Melbourne, Australia, 15-18 July 2012.

Geotechnical and Marine Geophysical Investigations of Near Shore Directional Drilling Alignments: A case study from the Hawkesbury River, Sydney

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ABSTRACT

Near shore conditions pose challenges when geotechnical investigations are undertaken for pipelines installed using directional drilling techniques beneath waterways. In this case study, geotechnical investigations incorporating marine geophysics were undertaken for an infrastructure project involving the installation of a wastewater transfer main beneath the Hawkesbury River between the then unsewered Dangar Island and Brooklyn on the mainland. The crossing involved a 1400 m long bore beneath tidal mud flats with variable water depths, a deep tidal channel and ground conditions that included a deeply incised palaeochannel and potentially faulted bedrock.

A desk study of published geological data, rock outcrop mapping and on-land borehole drilling formed part of the geotechnical investigation. In order to reduce the uncertainty of limited borehole data, and to address the challenges of obtaining subsurface information beneath the deep tidal channel without costly overwater drilling, a marine seismic reflection survey was completed. This mapped the bedrock profile, identified a possible fault and strong seismic reflectors within the bedrock near the centre of the palaeochannel at about 45 m depth. These, somewhat unusual strong seismic reflectors of limited lateral extent, were interpreted as regions of stress concentration in the Newport Formation created by valley bulging processes following rapid erosion. The geotechnical model inferred from these investigations was applied in the design of the directional drilling operation that was successfully completed in rock. This upgraded sewer system is now in operation and has removed a significant pollution source from the Hawkesbury River.

Keywords: directional drill, palaeochannel, marine geophysics, seismic reflection

1 INTRODUCTION

Sydney Water is delivering SewerFix, an infrastructure program that aims to protect public health and the environment by significantly reducing overflows and leaks from the wastewater system. From 2005 to 2007 the Brooklyn-Dangar Island scheme was constructed. This included the installation of a 150 mm diameter wastewater transfer main under the Hawkesbury River via a conduit created by the 200 mm diameter Horizontal Directional Drilling (HDD). This main linked the reticulation system on Dangar Island with a transfer main that follows Brooklyn Road to a treatment plant in the Seymour Creek valley at the western end of Brooklyn Road (Figure 1).

The lower Hawkesbury River is typical of a drowned river valley found on the east coast of Australia. Such systems formed when sea levels rose rapidly after the last ice age, some 18,000 years ago. These river valleys often feature relatively steep-sided palaeochannels (bedrock channels) formed by erosion during marine regressions as sea levels lowered during the ice age.

In order to assess the feasibility of a HDD between Brooklyn and Dangar Island, and to provide potential contractors with information for tendering and design purposes, Sydney Water commissioned a geotechnical investigation. HDDs pose less construction risk when the alignment stays within one material type, such as remaining entirely in rock or entirely in soil for the length of the bore. Other important aspects considered for this HDD included:

- The geometry and nature of the riverbed;
- The geometry and nature of the bedrock profile in the marine passage between Brooklyn and Dangar Island.

Two preferred HDD alignments were initially identified as shown in Figure 1. The marine section encompassing these alignments is approximately 650 m in length.

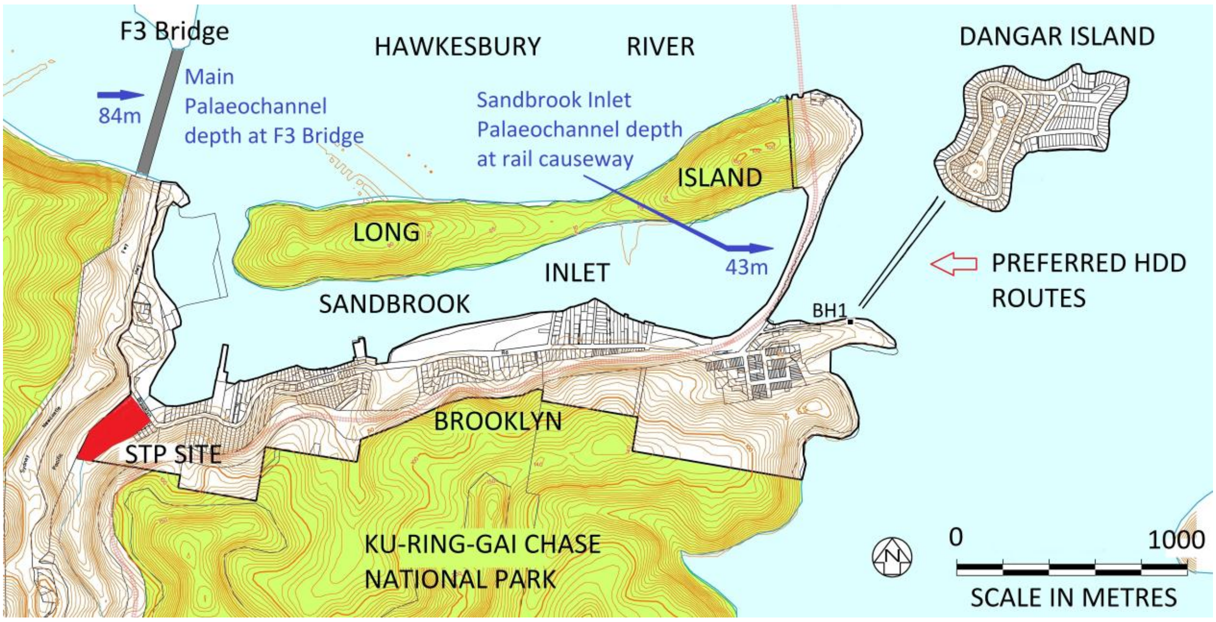


Figure 1: Site Locality Plan

This case study describes the investigation methodology, in particular the marine geophysical survey, site geology and the detailed interpreted subsurface conditions. The as-built details of the HDD are also presented.

2 INVESTIGATION METHODOLOGY

A desk study revealed that there was only limited geotechnical and geological data available and therefore further geotechnical investigations were required to provide a robust geological model. Dangar Island is only accessible by public ferry and private boat, and there are no commercial marine offload facilities or moorings, making mobilisation of a drilling rig to the island relatively costly. It was considered that drilling on the island would be of limited value as sandstone rock outcrop was widespread. Consequently, Sydney Water decided that investigations for the HDD on the island and at Brooklyn would be limited to surface mapping by an engineering geologist. This, together with mapping at Brooklyn, would allow further material properties and significant rock structures to be captured for correlation with borehole data, as well as assist in locating suitable entry points at Brooklyn and exit point on Dangar Island.

As drilling sites were more readily accessible near Brooklyn a single deep borehole was drilled in Lower McKell Park, near where the preferred HDD entry for both alignments intersected the shoreline. This borehole was drilled to 80 m depth to assess the bedrock conditions to below the likely HDD invert level.

Marine seismic reflection using continuous seismic profiling (CSP) was then completed in the area of the alignments to map the bedrock profile. This method had previously been successfully used in the rivers and estuaries of the Sydney region, although not without operational and technical challenges. The challenges included potential difficulties assessing the geometry of the bedrock surface where a relatively narrow and deep palaeochannel occurs beneath sediments containing possible gas layers and operation in very shallow water at some locations (< 1 m deep).

These challenges were met with a combination of marine seismic reflection with both low power (Boomer) sources and high power (Airgun) sources. The lower power, higher resolution Boomer source provided information on the shallower rock levels and the higher power airgun provided information on the deeper rock strata. The lower frequency of the air-gun signal reduced the influence of thin attenuating gas layers.

CSP relies on there being a relatively large seismic velocity contrast between the sandy sediments (seismic velocity approximately 1,600 m/s to 1,800 m/s) and the underlying sandstone/shale bedrock (seismic velocity approximately 2,000 m/s to 3,500 m/s) and a somewhat smaller density contrast (density approximately 1.8 t/m^3 to 2.4 t/m^3). Similar property contrasts were anticipated at the Brooklyn site. A recent example of a similar application of the CSP method for this purpose from Broken Bay, downstream of this site, is provided in Vrbancich et al. (2011).

The marine reflection survey was completed with both methods along two alternative proposed alignments (Lines 4 and 6, Figure 2) and shorter cross-lines at 50m intervals along these alignments. Bathymetric information was acquired at the same time as the marine reflection data and positioning was achieved using Differential GPS.

3 BACKGROUND GEOLOGY

The Sydney 1:100,000 Geology Sheet indicates the landfall sites for the HDD are underlain by Triassic age sub-horizontally bedded sedimentary units, namely the Hawkesbury Sandstone Formation and the Narrabeen Formation. In the Hawkesbury River area the Hawkesbury Sandstone Formation is underlain by the Narrabeen Group, primarily the upper sub unit known as the Newport Formation, comprising interbedded quartz lithic sandstone, siltstones and laminites.

The regional geology map shows the Newport Formation on the northern and southern shoreline of the Hawkesbury River. No obvious outcrops of Newport Formation rocks were noted on the southern shoreline of the Hawkesbury River in the Brooklyn area, hence the interface may be lower than that shown on the geology map. The investigation borehole drilled on the Brooklyn site of the HDD crossing encountered medium to coarse grained sandstone down to RL-0.1 m AHD and finer grained sandstone below this. The Hawkesbury Sandstone/Newport Formation intersection is therefore considered to be at RL-0.1 m AHD at the borehole location.

Test holes and piling records for the F3 Freeway bridge over the main Hawkesbury River channel to the west of the site (Figure 1) shows the palaeochannel infilled with alluvium to at least 84m below river level with the current channel floor about 20 m below river level. The palaeochannel depth at the mouth of the Hawkesbury River some 10 km to the east of this site is 125 m to 150 m below sea level (Vrbancich et al., 2011). Geotechnical investigations along the Brooklyn Rail Causeway across Sandbrook Inlet have indicated a palaeochannel at least 43 m below river level.

The presence of Long Island (Figure 1), being parallel to the southern shoreline of the Hawkesbury River and forming a barrier to the main river channel, suggests a separate watercourse (possibly originally Seymours Creek) may have incised into the bedrock to form Sandbrook Inlet. As such, the depth of the palaeochannel beneath the 750 m wide Sandbrook Inlet appears to be shallower than, and separate to the palaeochannel in the Hawkesbury River channel at the F3 bridge.

One of the major objectives of the geotechnical investigation for the Brooklyn-Dangar Island HDD was to assess whether the Sandbrook Inlet palaeochannel extends beneath the preferred HDD alignments or whether a deeper palaeochannel associated with the main Hawkesbury River palaeochannel exists.

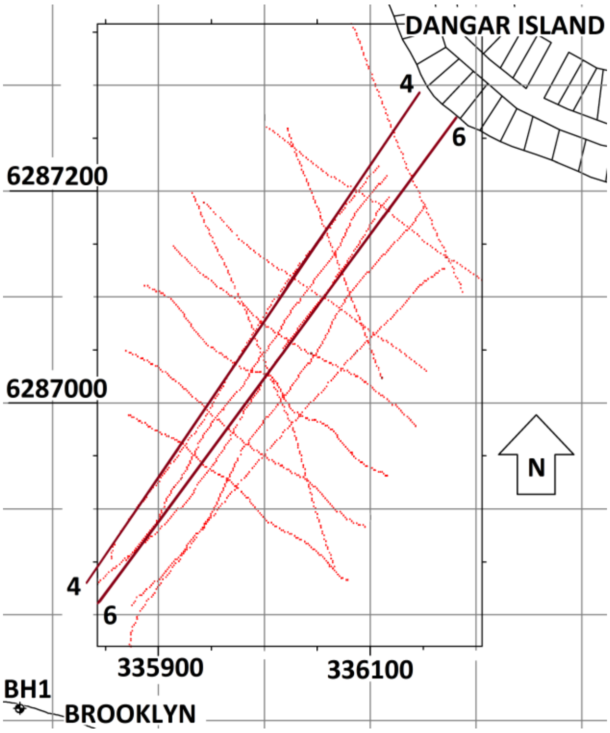
4 INTERPRETED GROUND CONDITIONS

The results of the borehole, BH1, on the Brooklyn shoreline (see Figure 1) indicate that the subsurface profile comprises fill (0.8 m thick), overlying residual soil (1.8 m thick) which overlies the sandstone (from the Hawkesbury Sandstone Formation) and interbedded laminite, shale and sandstone (from the Newport Formation of the Narrabeen Group).

The Hawkesbury Sandstone is relatively thin (1.5 m), and logged as a quartzose sandstone with cross-bedded, massive and lesser Siltstone facies. The Newport Formation was logged as predominantly quartz-lithic sandstone interbedded with siltstones, mudstones and laminate. The bedrock ranges from low and medium strength to a depth of about 19.8 m, medium and high strength to 24.5 m and high strength with bands of medium strength and very high strength rock to the termination depth of the borehole at 80 m.

River floor levels along the HDD alignments varied from about RL-3 m AHD to RL-12 m AHD between Brooklyn and Dangar Island. Levels rise abruptly on the Dangar Island side of the HDD alignments, which is consistent with the rock cropping out on Dangar Island.

Figure 2 shows the CSP lines and Figure 3 shows the interpreted bedrock contour plan based on all the seismic lines for the marine crossing in the area of the alignments with an interpreted fault and the approximate extent of an area where there was a strong sub-bottom reflector at depth. The bedrock rises abruptly to the north-east close to the landfall on Dangar Island and it is likely that this side of the palaeochannel is also faulted.



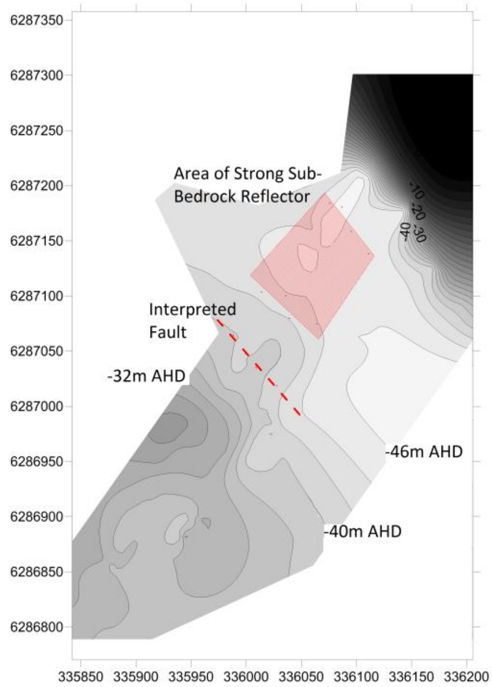


Figure 2 Marine Seismic Reflection Lines

Figure 3 Interpreted Bedrock Contours

Figure 4 shows a sample of the marine seismic reflection data acquired with the air-gun source along a part of Line 6.

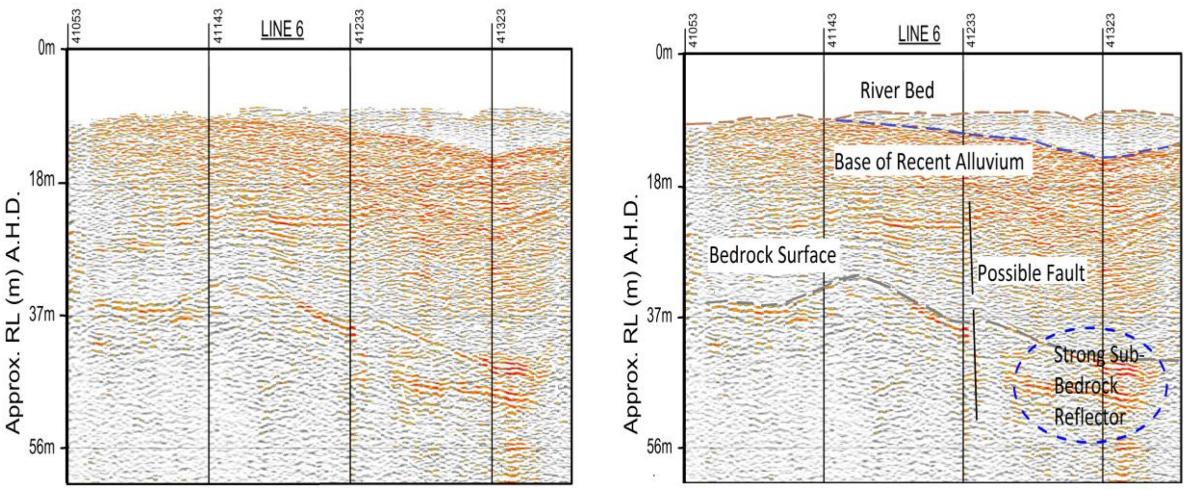


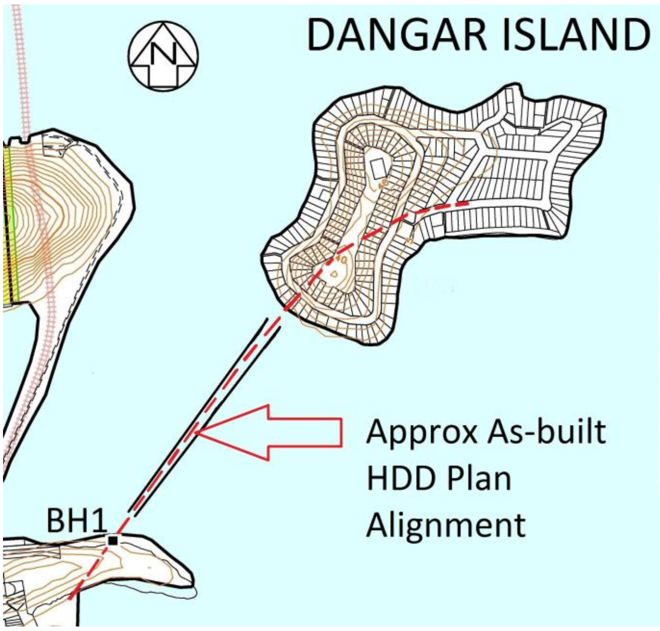
Figure 4 Sample of Marine Seismic Reflection Data without and with Interpretation

On the left of Figure 4 is the raw data (not tidally corrected) and on the right the data has been interpreted with the river floor, base of recent sediments and the bedrock reflector marked with dashed lines. There are other reflectors that are evident of this section including younger palaeochannels within inferred bedded sandy sediments but these have not been marked.

The bedrock reflector marked on Figure 3 is complex in shape and deepens to the north-east from about RL-37 m AHD to about RL-45 m AHD. This could be due to a combination of erosion and tectonic activity. A fault with possible shear zone from 5 m to 22 m in width near Station 41233 has displaced the bedrock surface and the overlying sediment reflectors. To the north-east of this fault, in the rectangular area shown on Figure 3, bands of strong sub-bedrock reflectors demonstrate an increased acoustic impedance (density x seismic velocity) that often indicates stress-concentrations that have been observed in earlier tunnelling operations in Sydney Harbour beneath palaeochannels (Whiteley, 2005).

5 AS-BUILT HDD DETAILS

Based on the rock levels predicted from the geotechnical investigation, the HDD was bored with 25 m to 35 m of rock cover. Figure 5 shows the ‘as-built’ record of the HDD plan and vertical alignments.



Entry Location:	Parlsey Bay - Boat Ramp Car Park - Brooklyn	
Exit Location:	Grantham St - Dangar Island	
Entry Angle:	12.6 Degrees (from Horizontal)	
Exit Angle:	23.5 Degrees (from Horizontal)	
Measured Length:	1407m	
Entry Coordinate:	E 335647.31	N 6286573.77
Exit Coordinate:	E 336600.08	N 6287537.88

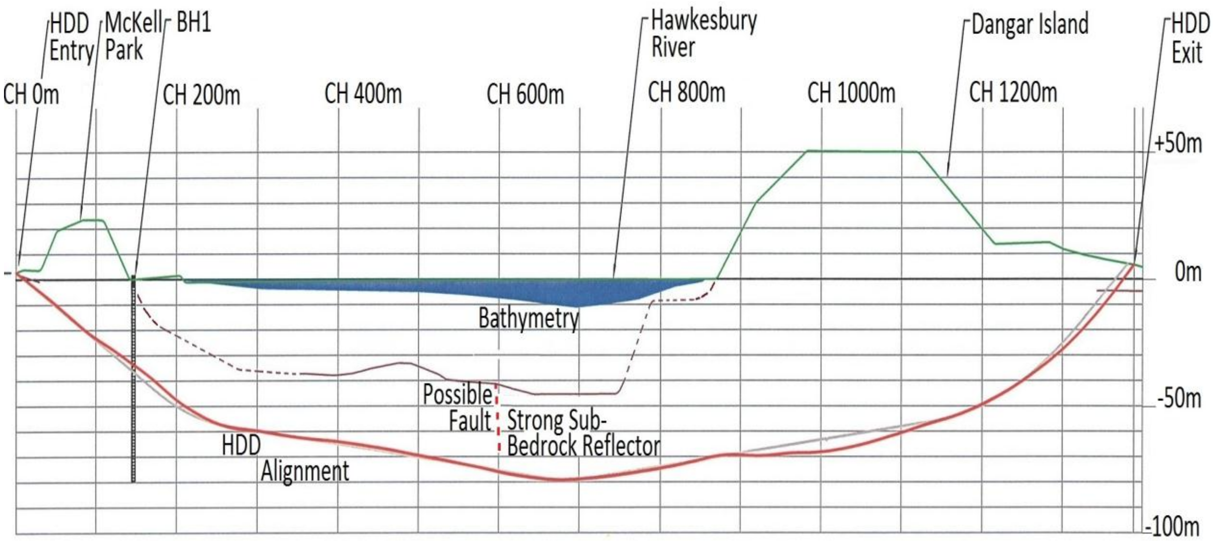


Figure 5 As-built HDD Plan and Vertical Alignment

Allowing 25 m to 35 m of rock cover was prudent, given the inferred likely faulting, and the potential high rock stress zone in the base of the palaeochannel shown in Figure 5. Such features increase the risk of drilling difficulty and increase the risk of 'frac-out' (drilling fluid breakout) if the HDD encounters poor quality rock or shallow rock cover. Anecdotal information from the HDD contractor indicated that the HDD may indeed have passed through a fault zone as indicated by the seismic survey, but was drilled without incident. The HDD was successfully constructed entirely in rock.

6 CONCLUSIONS

This project has provided major upgrades to the wastewater systems for the residents of both Brooklyn and Dangar Island.

This case study demonstrates the value of marine seismic surveys as a cost effective investigation technique, to assess subsurface conditions for HDD crossings in near shore and estuarine settings. Desk study information indicated possible palaeochannel depths varying from about 43 m (Sandbrook Inlet) to in excess of 84 m below river level (main Hawkesbury River). The results of the marine seismic survey indicate that the relatively shallow, Sandbrook Inlet palaeochannel extends to the east of the railway causeway and passes through the channel between Brooklyn and Dangar Island. This allowed the HDD route to be designed to remain in rock rather than encountering the deeper main Hawkesbury River palaeochannel and potentially encountering mixed rock and soil boring conditions.

Interpretation of the seismic reflection data provides opportunities to identify potential geological features such as faults and stress concentrations by providing contractors with information that can be used to plan HDD alignments to stay within geological units and to be prepared for, or to avoid, adverse geological structure such as faults or stress concentration zones.

7 ACKNOWLEDGMENTS

The authors wish to thank Sydney Water for permission to publish this paper, presenting details of the investigation and as-built details of the Brooklyn-Dangar Island HDD.

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