AN INVESTIGATION INTO IMPROVING THE FRESH WATER SUPPLY TO CHEUNG CHAU

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ABSTRACT: Cheung Chau Island is currently supplied with treated water from Silver Mine Bay Water Treatment Works on Lantau via two land mains running around the coastline of Lantau Island and two submarine water mains across the Adamasta Channel. The two submarine mains across the Adamasta Channel, 300mm and 500mm in diameter, were laid in 1963 and 1986 respectively. The 500mm main is normally used for supply with the older 300mm main serving as an emergency backup. As the older pipe does not have sufficient capacity to meet forecast demand, ways of improving the reliability of supply were investigated.

This paper describes the various options that were evaluated and outlines a modified horizontal directional drilling process that has been recommended as the preferred option for installing a new submarine pipeline to secure the future reliability of supply to the island.

1. INTRODUCTION

Cheung Chau is situated to the south-east of Lantau and, with a population of around 23,000, is the most densely populated outlying island. It is dumbbell-shaped with vegetated knolls in the north and south and a narrow strip of flat land in the central part which is bounded by a typhoon shelter to the west and Tung Wan to the east. The central lowland contains the development core where most of the existing village areas, commercial uses and major community facilities are concentrated.

Cheung Chau is currently supplied with treated water from Silver Mine Bay Water Treatment Works on Lantau. Treated water gravitates from Silver Mine Bay Service Reservoir to Cheung Chau Fresh Water Pumping Station via two land mains running around the coastline of Lantau Island and two submarine water mains across the Adamasta Channel. The two submarine mains across Adamasta Channel, 300mm and 500mm in diameter, were laid in 1963 and 1986 respectively. Water is then pumped from Cheung Chau Fresh Water Pumping Station to three existing service reservoirs on Cheung Chau from where it gravitates via distribution mains to consumers on the island.

The Adamasta Channel is a narrow passage between Chi Ma Wan Peninsula on Lantau Island and Cheung Chau Island and has a water depth ranging from 5 to 10m. It is the main traffic route for high speed ferry services between Hong Kong and Macau, several outlying island ferry services and river trade vessels.

Treated water is normally provided through the 500mm diameter main, with the 300mm main serving as emergency back-up. However, the maximum forecast mean daily demand for Cheung Chau in 2013 and beyond is about 9,500 m^3/day and the 300mm submarine main only has a capacity of about 7,600 m^3/day. In addition, the 300mm main is now approaching the end of its design life of 50 years. These two factors of increasing unreliability and under capacity led to the decision to investigate various means of improving the water supply to Cheung Chau.

The existing submarine main runs from Ha So Pai in the south eastern corner of Chi Ma Wan Peninsula on the southern boundary of Lantau South Country Park to Tai Kwai Wan on Cheung Chau – a distance of approximately 1.4km. Ha So Pai is a remote coastal bay that is not accessible by vehicle and can only be reached by foot along hiking trails or by boat. On the other hand, the landfall on Cheung Chau is at a beach that has a nearby flat area, is close to an existing water supply and is accessible to small vehicles along the narrow Cheung Kwai Road that runs from the main ferry pier.

2. PROJECT CONSTRAINTS

There are a number of significant challenges to be faced in this project. First of all, a portion of the works is located within the South Lantau Country Park, which is an environmentally sensitive area and the project is a designated project under item Q.1, Part I, Schedule 2 of the Environmental Impact Assessment (EIA) Ordinance (EIAO) (Cap. 499). In addition, there is much fishing activity nearby including the Cheung Sha Wan Fish Culture Zone (FCZ). Any dredging or other disturbance to the seabed is likely to have a major impact on the marine ecology and environment as well as the fishing industries.

Another major constraint is the very significant amount of marine traffic through the Adamasta Channel, which is one of the main channels for vessels entering and departing Hong Kong to the West, including frequent high speed ferries to Macau. Any construction obstructing this channel would pose significant difficulties and delays for this marine traffic.

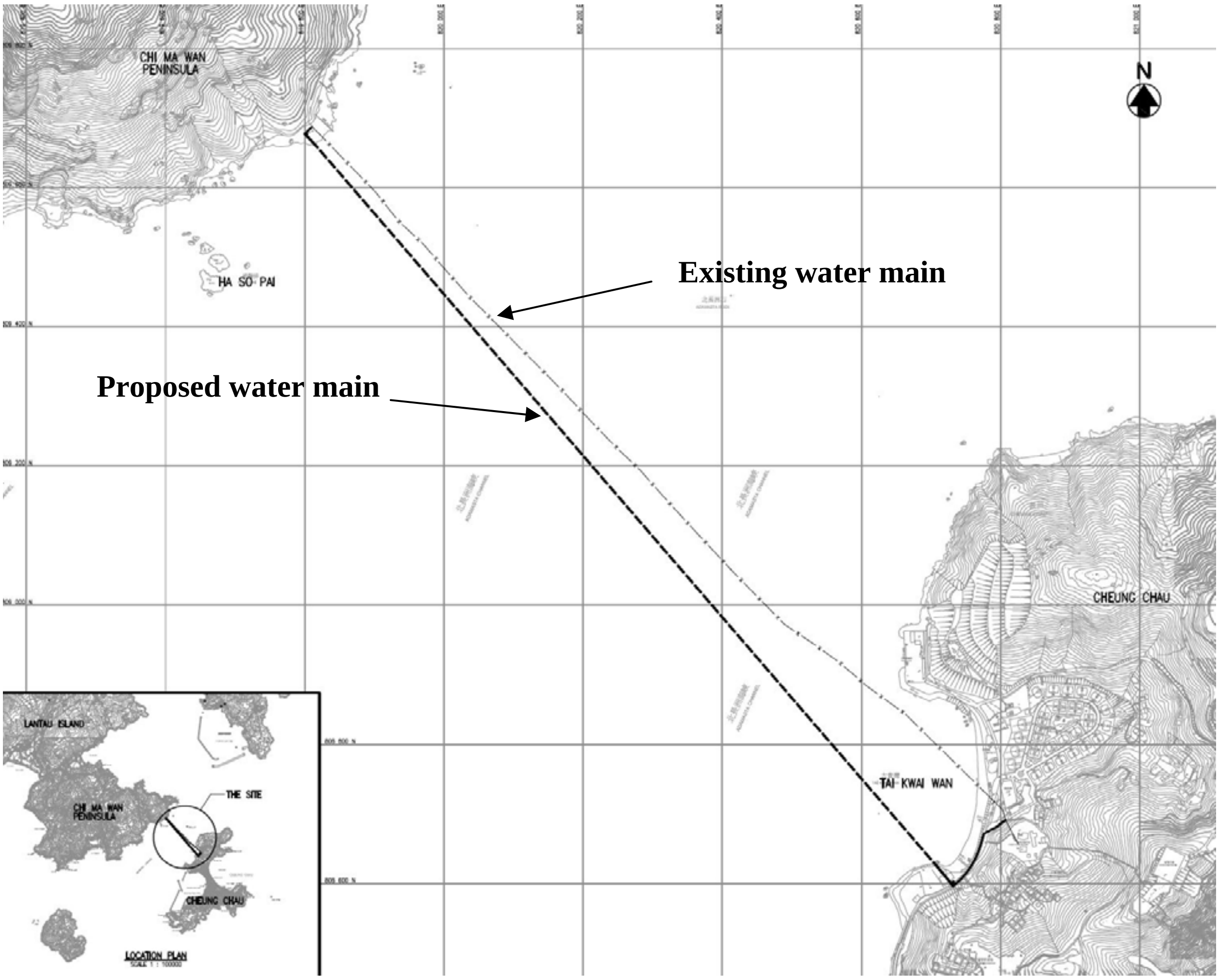

Figure 1: Project location showing alignment of existing and proposed water mains

3. OPTIONS FOR IMPROVING SUPPLY

Although a new pipeline is an obvious possible method of improving the adequacy and reliability of water supply to Cheung Chau, a number of options were investigated and evaluated, including:

i) a 500mm ID pipeline from Chi Ma Wan to Cheung Chau installed by conventional submarine trenching;

ii) a 500mm ID PE pipeline (with and without a steel casing pipe) from Chi Ma Wan to Cheung Chau installed by HDD;

iii) staged development - two 350mm ID diameter PE pipelines (with and without steel casing pipes) from Chi Ma Wan to Cheung Chau installed at different times to suit increases in demand;

iv) a 10km long submarine pipeline from Silvermine bay to Cheung Chau; and

v) a reverse osmosis desalination plant constructed on Cheung Chau.

3.1 Pipeline installed by Submarine Trenching

The most common methods for constructing submarine pipelines involve forming a trench in the sea bed, installing the pipe, and back filling. Trenching may be done by dredging or jetting and the pipe can be installed by lay barge, bottom pull, or float-and-lower methods. After the pipe has been placed in position, the trench can be backfilled by bottom dump, tremie, or other methods. An alternative is to simply lay the pipe on the sea bed with or without additional protection.

3.1.2 Dredging

Dredging involves the removal of marine sediment from the seabed to form a trench, into which the pipeline is laid. Dredging by grab dredger is commonly used in Hong Kong because it uses relatively light and readily available equipment and is low cost, but suction dredging is faster, more environmentally friendly but higher in cost. The potential for impacts on the water quality is high and excavated sediment will require disposal off site at a designated disposal ground.

3.1.3 Jetting

Jetting uses water jets to break-up, remove or liquefy the soil from under a marine pipeline allowing the pipeline to settle to an elevation below the seabed. The marine sediment in front of the jetting machine is fluidised to allow the pipeline to settle into the sediment. The sediment to be fluidised may be suspended in the water column and thus have an impact on the water quality.

3.1.4 Lay barge installation

The pipe can be installed into the trench by lay barge. Sections of the pipe are welded together on board a barge and the continuous length of welded pipe is allowed to descend from the barge into the trench. The barge moves slowly along the pipe route as new sections of pipe are welded together. The lay barge requires a considerable distance ahead and behind to allow the pipeline to descend into the trench. This can cause major problems in areas of busy marine traffic and the method is probably not suitable for short crossings.

3.1.5 Bottom pull

Pipes are assembled on land into a complete string or strings in which the first string is pulled on top of the seabed by a winch on the opposite side (or on a barge). The subsequent strings are jointed sequentially to the trailing end by welding as the pipeline is advanced along its alignment. This method typically applies to steel pipes, which are installed empty and then filled with water. The pipes have a concrete weight coat to make them just sink when empty and this fine balance of weight and buoyancy helps keep pulling forces low. Where there is not enough space, the pipes can be joined and pulled pipe by pipe or, if required, space can be formed from a temporary jetty or a moored flat top barge with launching ramp and welding facilities.

3.1.6 Float and lower

The pipe string is welded together and towed floating to the installation location. It is then lowered into position onto the sea bed by filling it or by filling attached buoyancy tanks. As the pipe string will float across the sea before lowering into position, marine traffic will be affected significantly during construction.

3.2 Horizontal Directional Drilling (HDD)

3.2.1 Conventional HDD

Horizontal Directional Drilling (HDD) involves drilling a pilot hole, typically 100 to 150 mm in diameter, and then progressively enlarging the hole, using reaming tools in steps of 200 to 300 mm, until the required diameter is achieved. Reaming is normally done in the reverse direction to the pilot boring and once the reamed hole has been fully formed, the pipeline is pulled into the reamed hole from the opposite of the crossing to the drill rig.

The pipe to be installed could be either steel, polyethylene (PE), or PE installed inside a steel casing pipe. The inherent flexibility of PE makes it relatively easy to install and allows for a reduced radius of curvature of the bore path compared with a steel pipe. A steel pipe must be adequately protected against corrosion by coatings and linings and possibly cathodic protection in order to ensure a long life. A bore of approximately 950mm diameter would be needed to install a PE pipe with internal diameter of 500mm inside a steel casing of approximately 750mm diameter.

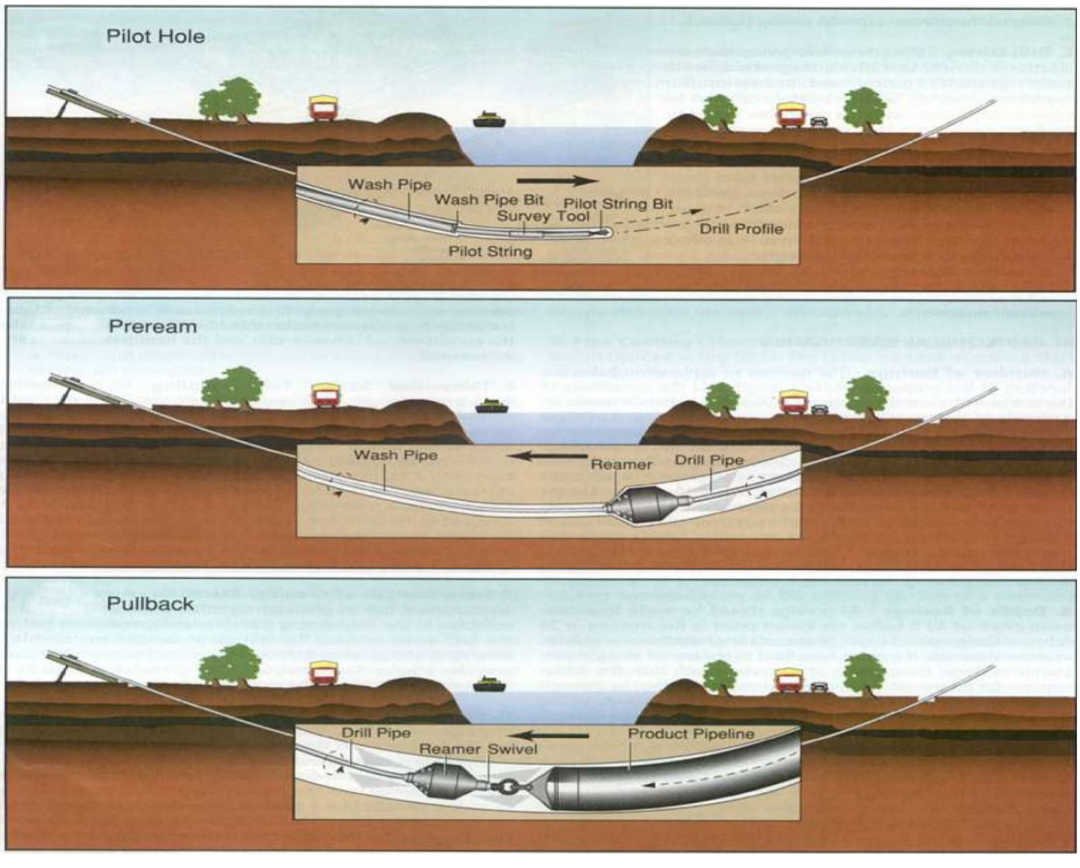

Figure 2: Typical horizontal directional drill (HDD)

HDD has developed over the past 20 years and drill lengths in excess of 2,000 m and diameters of 1,500 mm or even larger have now been installed so the combination of length and diameter for this project is well within the bounds of possibility for installation by HDD. The suitability of HDD for this project is largely dependent on the geotechnical conditions and the identification of suitable sites for the launching and reception of the drill and the pipe.

The bore path and pipe profile have to be quite deep in order to pass almost entirely through good rock and hence minimise the possibility of drilling fluid leakage from the bore. This requires long entry and exit transition curves at launch and reception. An entry angle between 8 and 15 degrees to the horizontal is normal and it is preferable that straight tangent sections are drilled before the introduction of a long radius curve. Long horizontal runs can then be made at the design depth before curving up towards the exit point, where the exit angle should normally be kept to between 5 and 10 degrees to facilitate handling of the product pipeline during pullback.

The radius of curvature is determined by the bending characteristics of either the product pipeline or the drill string depending on the pipe material, wall thickness and diameter. A steel pipe or casing will be relatively stiff and require a radius of about 1,000 times the diameter of the pipe, but this would be less for PE where the radius would normally be limited by the drill string rather than the pipe. The final bore hole needs to be large enough and accurate enough to allow the pipe to be pulled through successfully.

It is often a requirement that the pipe is welded together into a continuous string prior to being pulled into the bored and reamed hole in one continuous operation in order to ensure that there is no collapse of the hole. This presents considerable difficulties for this project due to the lack of suitable space and sites for welding and stringing out the pipe. However, providing that the hole is drilled through sound self-supporting rock it will not be necessary to continuously pull the pipe in without interruption, and sections of pipe can be welded up as the pipe is pulled into the hole.

Drilling fluid management is also an important factor to consider. Drilling fluid is composed of a carrier fluid (water) and additives, normally bentonite. During the drilling of the pilot bore, drilling mud will return to the inlet end (drill rig location) where it can be treated and recycled. However, during back reaming and pipe towing, drilling fluid is normally collected at the opposite side of the crossing to the machine from where it must then be treated and recycled to the machine for reuse. This can be avoided by adopting a forward reaming process whereby all the drilling fluid can be returned to the drilling rig end of the bore thus eliminating the requirement for transporting drilling mud from the exit end back to the rig. This has major logistical and environmental advantages.

HDD crossings offer maximum depth of cover and can be installed deep beneath the rock head profile at little or no extra cost, thereby affording maximum protection and minimising maintenance costs. They are inherently better protected from wave action, sea bed movement, and anchor damage than pipes installed on the sea bed or in trenches.

Construction of any submarine pipe line will have environmental and marine traffic impacts but, compared with conventional trenched methods, the environmental and marine traffic impacts associated with HDD are significantly less because the pipes are installed at considerable depths below the seabed without any construction activity on and above the seabed. Impacts will typically be limited to the entry and exit portals and along the alignment of any pipe strings during construction.

3.2.2 Constraints to HDD

However, there are a number of risks associated with long distance HDD that must be recognised and managed. The pilot drill or the reamer could become stuck in the hole. This usually occurs where loose ground is encountered such as at entry and exit points. The problem might be overcome by ramming a steel casing through the loose ground prior to commencing the drilling operation. The pipeline could also get stuck during the pulling process but this can usually be avoided by careful management of the drilling fluid and slurry and by ensuring that the hole is properly formed and thoroughly cleaned prior to inserting the pipe.

A further risk is that there can be a loss of drilling fluid into cracks and fissures in the surrounding rock or soil. This has both financial and environmental implications and mitigating action must be taken if there is any loss of fluid.

There must be sufficient space on one side of the bore to accommodate the drill rig, drilling fluid processing and pumping plant and other associated equipment, as well enough storage area for drill rods and consumables. On the opposite side of the bore there must be space available for welding up and stringing out the pipe, collecting and storing drilling fluid which must then be transported to the rig side for processing and reuse.

Although there is a suitable area to set up the drill rig and associated equipment on Cheung Chau, there is little available suitable land on the Chi Ma Wan side to site the drilling fluid treatment and recycling equipment and to string out a long length of pipe prior to installation. Therefore to minimise any adverse environmental impacts on the Country Park and the adjoining marine environment, a modified HDD process needs to be adopted whereby the main staging area and works are confined to the Cheung Chau side.

3.2.3 Modified HDD

In order to confine most of the work to the Cheung Chau side it will be necessary to insert the pipe from the drill rig side by pushing it in from the Cheung Chau side and/or using a winch positioned on the Lantau side to pull it in.

The likely procedures involved in doing this would be to first drill the pilot hole from the Cheung Chau side to within about 50 m of the exit but then retract the drill string to the drill rig side, attach the reamer and forward ream the hole in stages to the required diameter.

By stopping the bore before break through on the Chi Ma Wan side, all the drilling fluid and associated cuttings could be returned to the Cheung Chau side and there would be no need for drilling fluid recycling equipment to be located on the Chi Ma Wan side. All drilling mud mixing, cleaning and pumping equipment would be located on Cheung Chau.

Once the hole has been reamed to the required diameter, it could be totally cleaned of all drilling fluid by flushing it through with clean water for one or two days until the returns were completely clear, leaving a reamed hole full of clean water. The last few metres of drilling would then be done using only water rather than drilling fluid so that once the drill breaks through, only water will be released into the environment thus avoiding any contamination of the marine environment.

A winch could easily be set up on the restricted area of rocky coastline near the existing water main on Chi Ma Wan and a wire rope pulled through the bore to attach to the pipe on Cheung Chau which could then be pulled in gradually as the whole pipe length is welded up.

3.3 Staged development – two smaller pipelines

Two smaller diameter pipes from Chi Ma Wan to Cheung Chau could be installed in stages as demand required. The advantage of such a strategy would be that some capital cost could be deferred and also the installation of the second pipe would benefit from a thorough knowledge of the geophysical and environmental conditions that would have been gained during design and construction of the first one.

There would be a total of three pipes, rather than two, providing supply to Cheung Chau. Whilst this may provide greater security of supply, it may also be seen as extra responsibility in terms of operations and maintenance. If both pipes were installed during the same period of construction, environmental issues would be similar to those for the single pipe HDD option outlined previously.

3.4 Pipeline from Silver Mine Bay to Cheung Chau

Instead of constructing a new replacement pipeline to connect to the existing land based pipe at Chi Ma Wan from Cheung Chau, a longer pipeline which is 10 km long could be constructed direct to Silver Mine Bay WTW. This length is beyond the reach of HDD installation and construction would therefore have to be by one of the submarine trench methods.

The land based pipes which run around the Chi Ma Wan coastline connecting Silver Mine Bay to Chi Ma Wan are vulnerable to damage from land slides. A new 10 km long pipeline directly connecting Cheung Chau to Silver Mine Bay WTW would therefore provide a more robust supply for Cheung Chau.

However, a long pipeline to Silver Mine Bay would clearly have a greater environmental impact during construction than the shorter one proposed to Chi Ma Wan. In addition, there would also be a greater impact on marine traffic during construction because of longer construction period and greater extent of the work site in the sea.

3.5 Reverse Osmosis

An alternative to constructing a new pipeline to Cheung Chau would be to construct a reverse osmosis (RO) desalination plant on the island. The RO process takes salt water as feed and uses pressure to force pure water through semi-permeable membranes that inhibit the passage of salts.

The three most important limitations to the use of RO are the cost, energy consumption, and disposal of waste streams. In addition, other process specific issues such as feed water quality, location considerations, inlet and discharge pipes and diffusers, and availability and type of energy source can also limit its use. Desalination by reverse osmosis has been the subject of study and pilot plant trials in Hong Kong and has been shown to be technically feasible but a major disadvantage could be the high running cost. This is mainly because the RO process is energy-intensive, with energy consumption being typically around 4.0kWh per m^3 of water produced. A plant of 9,500m^3/day capacity would therefore consume approximately 38,000 kWh of electricity per day.

The estimated demand for Cheung Chau is 9,500m^3/day. Although the construction and operation of a plant of this size would present no major technical difficulties, it would require a site of at least 0.5 ha and it is unlikely that a suitable site of this size could be found on Cheung Chau.

4. EVALUATION OF OPTIONS

These options were each evaluated in terms of their capital and operational costs, technical feasibility, constructability, implementation programme, operation and maintenance issues, environmental impact, fisheries impact, cultural heritage impact and marine traffic impact.

Reverse Osmosis was ruled out at a fairly early stage due to the high capital and operating costs and the unavailability of land. The 10 km long submarine pipe direct to Silver Mine Bay was rejected on the grounds of the high cost, the environmental impact and the impact on marine traffic. It also became clear that there would be no benefit to be gained from the staged development option of installing two smaller pipes rather than a single one because of the longer construction time involved and the high cost.

Installing the pipe by submarine trenching is the lowest cost option as well as having the shortest construction period among all the options considered. However, the environmental impacts and the impact on marine traffic would be significant and considerably unacceptable.

The single PE pipe installed by HDD with no casing is the preferred option as it combines low cost, minimal environmental and marine traffic impacts and relatively short installation time. However, in light of the added benefit and security of installing this within a casing pipe, the single PE pipe inside a steel casing is the recommended option.

HDD is the preferred option but with innovative forward reaming together with product pipe installation from the drill rig side. Using this adaptation of HDD it will be possible to practically eliminate activity on the Lantau side and thus avoid environmental impacts on the marine waters of the Southern Water Control Zone and on Lantau South Country Park.

5. SITE INVESTIGATIONS AND DESK STUDIES

Desk studies and site investigations were carried out to confirm the feasibility of the preferred option; these included geotechnical investigations, identification of land requirements, geophysical seabed surveys, marine investigations, sediment quality assessment, marine and land archaeological investigations, utility investigations, environmental assessment and public consultation exercises.

5.1 Geotechnical

The site is underlain by medium to coarse grained granite and intrusive feldsparphyric rhyolite, contact of those two rock type have been found in one of the drillhole. The rock head level ranged from -11.40 to -35.65 mPD, descending from shore to middle of the channel generally.

From the geophysical data, the thickness of marine deposit, including marine mud and marine sand at the channel ranged from 5.7m to 11.45m and the thickest zone is noted at the central of the channel, except the rock outcrop near Chi Ma Wan Peninsula. No general trend was found in the geophysical isopach of alluvium; the alluvium layer is uneven and ranged from 2.0m to 14.0m across the channel. The saprolite layer is relatively thin near both shores and is found mainly at the middle portion (approximately 450m wide) of the channel.

From the site specific Marine GI works, only limited natural transported soils are evident in the Adamasta Channel close to Cheung Chau. The site is overlain by a considerable depth of marine deposits; the depth of the marine deposits ranges from 5.7 m to 11.45m.

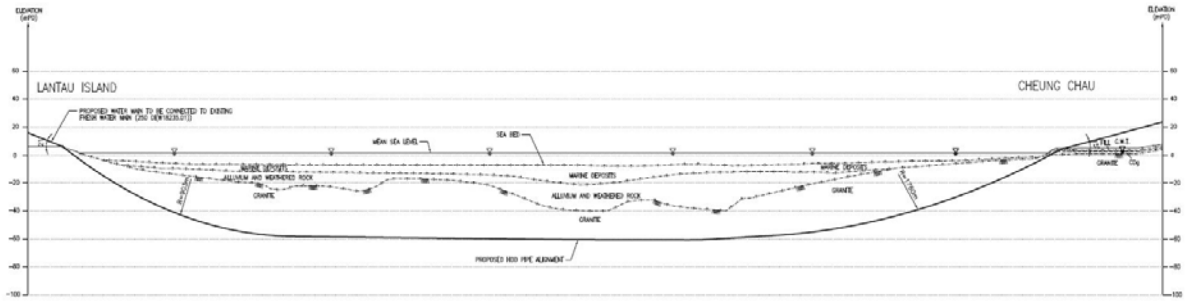

Figure 3: Proposed HDD bore path

5.2 Geophysical Seabed Surveys

The purposes of the geophysical seabed surveys are to measure the seabed level; to reveal the general distribution of geological material beneath the seabed and the features on the seabed; and to verify the alignments of the existing cables and pipelines.

The geophysical surveys were carried out in 2008 at Adamasta Channel. Four different kinds of surveys which included echo sounding and swath survey, seismic profiling survey, side scan sonar survey and magnetic survey were undertaken. The echo sounding and swath survey is to measure seabed levels in detail. The seismic profiling survey is to identify the geological succession over the water mains corridor. The side scan sonar survey is to find objects at or above seabed, such as rock outcrops, dumped materials and other artificial objects. The magnetic survey is to detect the alignment of the existing pipelines and cables.

The results of the geophysical surveys were given in form of contour plans, graphical and tabulated data in for designing the alignment of the proposed submarine pipe. The seabed level varies from 0 mPD to -8 mPD at the Adamasta Channel. The major seabed features, the existing cables and pipelines were also located.

The results of geophysical seabed survey would be less critical for determination of alignment of the water main which is installed by HDD method instead of traditional submarine trenching, because the bore path will be well below the seabed.

5.3 Environmental Assessment

An EIA study has been carried out and the key environmental issues such as water quality, ecological impact, fisheries impact, cultural heritage impact, construction waste management, construction noise have been addressed.

The modified form of HDD has been recommended for this project thus minimising the environmental impact and ensuring that the seabed will not be disturbed. The only possible impact would come from the working pit on Cheung Chau. However, as forward reaming is proposed, all the dirty works would be carried at the launching site on Cheung Chau, for which there is adequate working space and necessary mitigation measures, such as concrete bunds to avoid drilling fluid from flowing out into the sea, can put in place.

6. CONCLUDING REMARKS

The various alternative solutions have been considered, and the preferred option is a modified form of HDD. The modifications have been selected to overcome some of the land, access and environmental constraints.

Various site investigations have been carried out and the conclusions are that, although more detailed investigations should be carried out at the detailed design stage, the HDD proposal provides a technically feasible and economically attractive solution to the problem of enhancing the water supply to Cheung Chau.