Case Study on the Strategic Tunnel Enhancement Program (STEP)

R. H. Marshall¹, S.H. Orakzai²
¹CH2M HILL, Abu Dhabi, ²Abu Dhabi Sewerage Services Company, Abu Dhabi, UAE

1. Introduction

The United Arab Emirates (UAE) has achieved remarkable social and economic accomplishments over the past few decades. In particular, the Emirate of Abu Dhabi has witnessed major growth in its residential and commercial sectors, with the capital city of Abu Dhabi undertaking numerous large-scale developments which follow a very aggressive timescale. As part of its Plan 2030 master plan, the Emirate noted that many of its sewerage assets are overloaded and nearing the end of their intended service life. Given Abu Dhabi’s international reputation and image, combined with the population growth that is projected for both Abu Dhabi island and the mainland, the need for an efficient, adequate, and reliable wastewater management system is vital.

The Abu Dhabi Sewerage Services Company (ADSSC) is a semi-governmental organisation, which owns and operates all sewerage networks and treatment plants throughout the Emirate of Abu Dhabi. The ambitious pace of development and economic growth is posing major challenges for the existing sewerage infrastructure and many assets are unable to meet the demands being placed on the system.

ADSSC has adopted a proactive strategy to stay several steps ahead of Abu Dhabi’s infrastructure needs, and has launched a major investment program to expand and improve the sewerage system. In 2006, ADSSC commissioned a report entitled “Master Plan for the Sewerage Network in the Emirate of Abu Dhabi” and used this report, along with other historical data sources, to develop a series of carefully planned investments. The resulting Capital Investment Program (CIP), is intended to address both strategic and conceptual needs, and comprises several long-term development plans, the most ambitious being the Strategic Tunnel Enhancement Program (STEP) (refer to Figure 1 below).

In addition to CIP, several wastewater treatment projects are being implemented by ADSSC:

- Mafraq Wastewater Treatment Works (WWTW) Enhancement – a project to enhance the treatment capacity of the existing Mafraq plant
- Two new wastewater treatment works at the Al Wathba site – these projects will provide a total of 600,000 m³/day of treatment capacity by 2012

In February 2008, ADSSC appointed CH2M HILL to a six year consultancy services agreement, to serve as Program Manager for the delivery of STEP. An integrated Program Management Office (PMO) was created, comprising CH2M HILL staff and a small number of Emirati and expatriate secondees from ADSSC. The timescale for delivery of the STEP program is as follows:

2008: Validate and develop the initial studies, undertake the preliminary design of the STEP components, develop bid documents
2009: Issue bid documents for all STEP components, evaluate bids and award construction contracts
2010-2012: Detailed design and construction of STEP
2013: Complete commissioning and testing, divert flows from existing system into STEP and commence operation of the new system
This paper will describe the STEP components and the risk management process behind the key decisions that were made in the first year of the program. These decisions shaped the program, in terms of both the physical works and the method of delivery.

Figure 1
Major Capital Investment Plan (CIP) Components

2. STEP Components

STEP features three key components, including a deep sewer gravity-fed tunnel several link sewers to transport the wastewater to the treatment plants, and a main pumping station. The STEP concept is to use the link sewers to intercept the flows from existing gravity sewers upstream of the existing pumping stations. By intercepting the flows, the link sewers will relieve the existing main collector system and eliminate the need for up to 35 existing pumping stations, which are nearing capacity and require extensive maintenance. These flows will be channelled by gravity via the deep tunnel sewer to centralized wastewater treatment facilities. A new pumping station will lift the sewage into the treatment works, where it will be treated and reclaimed as treated sewage effluent (TSE) for return to the metropolitan area for irrigation purposes. Six major contracts are anticipated to be awarded during the construction of STEP.

2.1 Deep Tunnel Component

The new deep tunnel sewer will extend over 40 kilometres from the existing Main Pumping Stations on Abu Dhabi Island, across the mainland to the existing Mafraq Wastewater Treatment Plant (WWTP) and then to Al Wathba Independent Sewage Treatment Plants (ISTPs), currently under construction.

A total of eight Tunnel Boring Machines (TBM's) will be used to excavate the tunnel and install the bolted segmental pre-cast concrete structural lining. There will be three TBM’s at approximately 5m in diameter, three at 6m in diameter and two at 6.5m in diameter. The pressurised face TBM’s specified by the PMO are capable of excavating the tunnel at a rate of 100m per week in the anticipated ground conditions of Siltstone, Mudstone and Gypsum, without causing adverse surface settlements.
Approximately 1.2 million cubic metres of excavated material will have to be removed from the tunnel to disposal sites.

In the 12 month period that will be required for the TBM’s to be designed and manufactured, the contractors will complete the detailed design of the works and excavate and line the work shafts at nine locations along the tunnel route. These shafts will serve to launch and receive the TBM’s and will vary between 9.0 and 20.0 m in diameter. The tunnel will start approximately 20 metres below the ground surface and will reach a depth of up to 80 metres at the downstream end of the tunnel at Al Wathba (with a constant gradient of 1:1300).

After completing the excavation and the installation of the primary (structural) tunnel lining, a double corrosion protection lining will be installed. This dual corrosion protection lining will comprise a High Density Polyethylene (HDPE) primary lining cast into an *in situ* concrete secondary lining. This double system is very robust and is designed to provide 80 years of maintenance free protection to the structural lining of the tunnel from attack by the sulfuric acid which is generated by the sewage.

The deep tunnel sewer is designed to provide self-cleansing velocities, thus will require minimal maintenance requirements. Access shafts will be provided along the tunnel route at 2.5 kilometre intervals, which will allow future inspections of the deep sewer tunnel using remote operated vehicles (ROVs).

### 2.2 Link Sewer Component

Over 50km of link sewers, varying in diameter from 800mm to 3.1m will be used to connect the existing sewerage system to the new deep sewer tunnel. These link sewers will replace the existing pumping stations and pumping mains by conveying flows from the collection system to the deep tunnel by gravity. The range of diameters proposed for the link sewers will be constructed through the use of microtunnelling. Trenchless construction is preferable to open-cut construction techniques in order to minimise the impact on traffic, commerce and daily life on both Abu Dhabi Island and the Mainland. As with the deep tunnel, the link sewers are designed to provide self-cleansing velocities, thereby minimising maintenance needs.

### 2.3 Pumping Station Component

A single new pumping station will be developed at the downstream end of the new deep tunnel route, just before it reaches the Al Wathba ISTPs site. This station will have the peak pumping capacity of approximately 1.7 million cubic metres a day (31.1 m$^3$/sec) and, at over 100m deep and 60m in diameter, it will be one of the largest pumping stations in the world.

### 2.4 Enabling Works Component

The preliminary geotechnical investigation for the deep tunnel was carried out during a nine-month period from June 2008 to February 2009, using two geotechnical investigation contractors. They were required to perform the fieldwork, prepare the boring logs, carry out laboratory testing and provide geotechnical data reports. The investigations comprised the drilling of exploratory boreholes, disturbed sampling of soils, rock coring, *in-situ* testing and surface based geophysical surveys. The geophysical surveys comprised seismic refraction, electrical resistivity tomography (ERT) and time electromagnetic method (TEM).

Eighty-five exploratory boreholes were drilled along the deep tunnel alignment. The planned interval was one borehole every 500 m along the alignment, but the actual intervals varied due to drilling rig access or permitting requirements. Borehole depths varied between 35 m and 101 m. The depth of bedrock varied between 4.2 m and 25 m below ground surface (bgs), with an average depth of 11 m bgs.

Information from this preliminary geotechnical investigation will be supplemented by the design-build contractors being required to undertake further exploratory drilling early in the detailed design phase of their contracts.
3. RISK MANAGEMENT PROCESS

The earlier in the initial scoping and design process that a potential risk to the construction of underground works is identified, the greater is the opportunity to remove or mitigate that risk. During the first year of STEP, a key task was the identification of risks and the incorporation into the preliminary design and the contract documents the means to manage and mitigate these risks. Based on the outcome of the risk management process, key decisions had to be made in the following areas:

- Preliminary design and contract specifications
- Contract packaging
- Form of contract/delivery options
- Risk apportionment
- Contractor pre-qualification/bid evaluation

The following sections discuss each of these considerations.

3.1 Preliminary Design and Contract Specifications

Once risks are identified during the design phased, they may be dealt with in several ways, including:

- Design of features that will reduce or eliminate risk, e.g. selection of tunnel alignment to avoid known adverse ground conditions
- Specification of the methods of tunnelling and shaft construction that will minimise the risks. However, there is a fine line between ensuring that appropriate controls are included in the contract documents and in going too far, i.e. in specifying the means and methods the contractor shall employ
- Specification of the monitoring and controls to be implemented during construction that will warn against impending risks

Although much can be done to mitigate tunnelling risks and the effects of risk events, risks cannot be completely removed from the construction of underground works. Some of the key risks identified in the STEP design phase are as follows:

3.1.1 Ground Conditions Risk

A major factor in the mitigation of ground conditions risk is the quality and coverage of the Site Investigation work. The greater the effort that is put into identifying the true nature of the ground conditions along the tunnel route during the pre-construction phase, the greater the reduction in ground conditions risk to both ADSSC and the contractors.

The following ground conditions risks may be present along the STEP routes, thus the PMO included various risk mitigation measures in the preliminary design and the contract specifications:

- **Solution features in the Gypsum.** To deal with the risk of encountering a large solution feature or “cavern” in the Gypsum, the PMO has specified that the TBM’s are fitted with drilling rigs for forward probing and grouting. The TBM’s should only excavate in probed ground. Other mitigation measures are the Site Investigation (SI) work and the ability to ‘grout up’ any small caverns identified in the SI work. This work would be done from the surface, in advance of the TBM arriving. If a large cavern (i.e. larger than the TBM) was identified in the SI work (which is considered unlikely at tunnel horizon), then the tunnel route would have to be adjusted to avoid it.

- **Deep pockets of cohesionless sand as infill to solution features.** To deal with flowing sand, the PMO specified the use of pressurised face TBM’s. If loose sand is discovered when entering the cutterhead chamber for an inspection or changing of the cutterhead tools, then the intervention should be abandoned and the TBM driven into more stable ground conditions. If this is not possible, then ground treatment in the form of grouting or ground freezing undertaken from within the TBM may be necessary.

- **Highly permeable strata with large flows of ground water.** To mitigate this risk, the PMO specified the use of a pressurised face TBM in combination with effective tailskin seals, pressurised grouting of the tailskin void through the tailskin (not through the segments) and precast concrete
segments fitted with gaskets along all joints. In face interventions, the use of back loading cutter tools has been specified so that the tools can be changed from within the TBM cutterhead chamber. Also, compressed air has been required as a method of ground treatment. By pressurising the cutterhead chamber, groundwater can be prevented from flooding the chamber during interventions. The ability to grout through the cutterhead to treat the ground in front of the cutterhead is another method that can be used (sometimes in combination with the use of compressed air) to exclude water from the chamber during interventions.

Other, more general ground conditions mitigation measures were incorporated in the contract specifications for the STEP tunnelling works:

- Pre-construction surveys of structures in the zone of influence of the deep tunnel sewer. All buildings, structures and major services within the zone of influence are required to be inspected and assessed by the contractors.
- Monitoring of the movements of the ground surface and any buildings, structures and major services within the zone of influence of the tunnel.
- Monitoring of ground water levels through piezometers, located in site investigation boreholes.
- Submission of detailed methods statements, including accompanying risk assessment by the contractors for PMO review and approval before starting any new operation.

3.1.2 Schedule Risk

The construction of STEP comprises the following sequential activities: procure the TBM’s, excavate the tunnel (installing the structural lining concurrently), install the secondary corrosion protection lining, and complete the permanent shafts. Each operation cannot start until its predecessor has been completed. A delay to any of the four operations becomes a critical delay to the contract and, possibly, to the entire schedule of STEP. Because tunnelling is a linear activity, it is nearly impossible to recover from any delay that might occur.

ADSSC requires that the deep sewer tunnel system become operational no later than 2013. The duration of the preliminary design phase and the tender documentation and evaluation phase leaves 3.5 years to 4 years for detailed design, construction and commissioning of the system. The deep sewer tunnel is on the critical path for the whole program. The timeframe for the design, manufacture and delivery of a TBM is approximately 12 months, leaving only 3 years for the remaining activities.

To mitigate the risk of delays to this challenging schedule, the PMO incorporated various measures in the preliminary design and in the contract specifications:

- TBM Procurement - Use a Design/Build delivery approach so that detailed design can be done in parallel with TBM procurement
- TBM Excavation
  - Use more TBM’s – the PMO decided to break down the STEP route into 5 km sections, thus requiring eight TBM’s, working concurrently to complete the excavation on schedule
  - Specify suitable and reliable TBM’s – the PMO specified the use of new, pressurised face TBM’s and that spare parts for long lead items be provided with each TBM upon delivery
  - Specify that the TBM is fit for purpose – ensure that it is designed to excavate effectively through the known ground conditions and that it has the ability to cope with conditions that are more adverse than expected

Although some of the major risk mitigation measures can be implemented by the PMO through its design and contract specifications, other measures will be the responsibility of the contractors to implement. However, the PMO will be proactive in encouraging and managing the contractors to implement such measures that are necessary to ensure that schedule goals are achieved. Examples of contractor mitigation measures are:

- Ensure that experienced TBM operators and supervisors are employed
Incentivise the workers to perform by paying bonuses related to, say, the number of tunnel rings built per day – although sometimes this strategy has been known to have a detrimental affect on workmanship

Ensure that the TBM is operated and maintained in accordance with the manufacturer’s guidelines and insist that a representative of the manufacturer is based on-site

Ensure tunnel lining segments are robust and meet the specified tolerances – and ensure timely delivery of segments

To summarise this section, the contract specifications and drawings issued to the Design/Build bidders incorporated all the risk mitigation measures identified by the PMO during the preliminary design phase. The Employer’s Requirements in the Contract (i.e. the specifications, drawings and other documents) establish a baseline or a minimum standard that the design/build contractor has to achieve in the detailed design and construction of STEP. Thus, all the risk mitigation factors identified by the PMO have to be incorporated into the contractor’s detailed design and construction means and methods. The production of robust designs and contract specifications are a major means of managing risk in underground works.

3.2 Contract Packaging

As described in Section 2, STEP comprises a deep tunnel, link sewers and a pumping station.

Awarding a single contract package was not practical, or desirable because of the significant budget of STEP (over AED 8 billion or USD $2 billion when estimated in November 2008), so deciding how to minimise risk by dividing the program scope into smaller packages was an early task for the PMO. This breakdown could have been based on either the type of construction work or the geographic location of the construction work. The PMO opted to break down the scope based on the type of construction work.

The deep bored tunnelling work is a specialist construction activity, and the PMO recommended that this work be packaged separately from the other elements of the scope of work, to attract international tunnelling contractors with experience in deep tunnelling work, using pressurised face Tunnel Boring Machines (TBM’s). A single contract to construct the 40km of tunnel was considered to be too large for a single contractor or Joint Venture to manage (estimated at AED 4 billion or over USD 1 billion). When the lengths of drives and the number of TBM’s required were taken into consideration, PMO decided to break the work down into three contracts: two contracts with 15km of tunnel using three TBM’s and one contract for 10km of the deepest section of tunnel using two TBM’s. The contracts were considered large enough to attract the most prominent tunnelling contractors from around the world. This assumption proved to be correct, and the preeminent international tunnelling contractors responded to the prequalification request.

The link sewers will be undertaken by pipe-jacking methods. Although the link sewer work could have been incorporated into the deep tunnelling packages, by doing so, the tunnel packages would be increased to a very significant size and value, with additional program risk. A further consideration was that there are a number of local companies that have experience in micro-tunnelling in the UAE, but these companies would not be qualified to undertake the larger diameter deep tunnel sewer. To satisfy one of ADSSC’s objectives to “provide opportunities for local contractors and suppliers”, PMO recommended that the link sewer work be bid as a separate packages from the deep sewer tunnel work. The estimated value of the link sewer contracts was AED 1.5 billion, so this work was broken into two separate contracts, defined by the geographic location of the sewers.

In view of the size (in cost terms) and the type of construction work involved (general civil, electrical and mechanical), PMO recommended that the Tunnel Pumping Station be bid separately from the other sewer components of STEP, and as a single contract.

3.3 Form of Contract/Delivery Options

3.3.1 Form of Contract

Numerous approaches could have been used for delivering the STEP facilities, including:
• Traditional design/bid/build
• Design/Build (D/B)
• Design Build Operate (DBO) or Build Own Operate Transfer (BOOT)
• Alliance

Given the need to have STEP operational by 2013 and the nature of the proposed STEP components, a Design/Build (D/B) delivery method was recommended as the most suitable for implementation of STEP:

• D/B is a proven delivery approach for tunnelling works (either bored tunnels such as the deep tunnel sewer or micro-tunnels such as the link sewers) and it has a successful track record on numerous major tunnelling projects around the world
• New facilities on open sites, such as the proposed pumping station, are ideal facilities to be implemented under a Design/Build approach, using contractual boundary conditions and performance based requirements
• D/B allows the contracts to be awarded in the shortest period of time
• Tunnelling work is very amenable to a D/B approach, since it allows the contractor to closely coordinate and manage the detailed design with the planned construction techniques and equipment and enables the detailed design of the works to be undertaken in parallel with TBM procurement. This reduces the overall delivery period
• The overall risk to ADSSC is reduced, since the contractor manages the interface between the designer and the construction team

3.3.2 Conditions of Contract

PMO recommended using the new Abu Dhabi Government Conditions of Contract for STEP, which are based on a (slightly) modified FIDIC contract. The FIDIC Design/Build conditions have been used successfully on many tunnelling projects world-wide. The Abu Dhabi conditions have been approved by the Abu Dhabi Government for use on all its contracts, hence its use on STEP is entirely appropriate. Because the PMO proposed that all contracts be delivered using a Design/Build contract, the Abu Dhabi Government Conditions of Contract for Design/Build Works were recommended for use on STEP.

3.3.3 Method of Measurement

Another risk management/mitigation consideration relates to method of measurement or form of payment. The PMO recommended that the payment mechanism for the Design/Build contracts should be Lump Sum. Remeasurement is not appropriate for Design/Build, since the design is only at the 30 percent stage when the contract is bid, so it is not possible to produce a detailed Bill of Quantities. Target gain/pain share contracts have been used on other international Design/Build works, but are not recommended for STEP, since it is untested in the UAE market, and would have introduced a new element of risk to the program.

3.4 Apportionment of Risk

In proposing multiple construction contract packages, the use of the design/build form of contract and the use of a lump sum method of measurement, risks have already been apportioned between ADSSC and the contractors. The Conditions of Contract is another key document, that assigns risks to the parties to the contract. For the STEP contracts, certain amendments to the Abu Dhabi Conditions of Contract have been incorporated as discussed in the following subsections.

3.4.1 Unforeseen Physical Conditions

In drafting the new Abu Dhabi Government Conditions of Contract for Design/Build Works, the Government took the view that in Design/Build contracts, the contractor should retain the unforeseen physical conditions (UPC) risk since it is best able to "design" its way out of any problem that might be encountered. However, for tunnelling works, the risk of unforeseen physical conditions (UPC) are usually assigned to the Employer, since the Employer is the best party to own that risk, i.e. ADSSC would only incur costs if a UPC was actually encountered. Ultimately, the PMO recommended that the
Abu Dhabi Government Conditions of Contract for Design/Build Works be amended, to place the risk of encountering UPCs on the Employer, and not on the Contractor.

3.4.2 Insurance

Insurances for the Works can be provided by either party to a contract. The new Abu Dhabi Government Conditions of Contract require the Contractor to provide all insurances. However, for large programs with multiple contracts and contractors, it has been demonstrated that large and influential Employers can negotiate a better insurance package, than individual contractors. Using this approach, the overall risk and cost of the program can be reduced by the Employer providing its own insurance cover. The PMO recommended that ADSSC procure an Owner Controlled Insurance Program (OCIP) for STEP, which required an amendment to the General Conditions of Contract.

3.5 Contractor Pre-Qualification

The final risk management/mitigation consideration during the design phase of the program, was related to the pre-qualification of the construction contractors. Numerous construction contracts were recommended, but to gain the positive risk mitigation measures from this approach, it was important to ensure that only the most experienced contractors were allowed to compete for these contracts. The PMO developed a robust process for pre-qualifying contractors, according to experience and expertise in each of the three main STEP components: the deep sewer tunnel, the link sewers and the pumping station.

4. Conclusion

A significant amount of work has taken place to get the program to this point, but STEP is firmly on track and being delivered according to schedule.

As of December 2009, bids for all the contracts have been returned to the PMO. The first deep tunnel contract for the central 15km tunnel was awarded to Impregilo SpA of Italy in September 2009 and construction work is underway. The awarding of the remaining two deep tunnel contracts is imminent. No unacceptable bid qualifications were received and the bid prices have been very competitive.

It was encouraging to ADSSC and the PMO that the bid queries received from bidders for all contracts did not identify any major issues or flaws with the bid documents. All bidders appeared to be comfortable with the decisions made in each of the five key areas described above (refer to sections 3.1 to 3.5).

In other areas, all route approvals, environmental approvals and the approvals to reserve plots of land for the tunnel drive sites and the pumping station site have been obtained from the Abu Dhabi Authorities.

ADSSC and the PMO are confident that the hard work put into the design phase in identifying, managing and mitigating program risks will facilitate STEP completion by 2013.