PUBLIC TRANSPORT: THE KEY TO BALANCED URBAN GROWTH AND SERVICE DELIVERY

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The current state of national service delivery is not fulfilling the increasing urban needs. The present urban dynamics create a structure that enables ad hoc peripheral developments and encourages urban sprawl, causing major problems for service delivery. There are three approaches that address the imbalance of service delivery. The 'do-it-all' approach deals with the area's lack of services in its entirety. It is similar to a 'band aid' approach whereby all the insufficiencies are attempted to be dealt with on a short term, quick fix basis. The 'backlog eradication' approach deals with service delivery by focusing on the eradication of historical backlogs. The 'catalytic' approach is a balanced approach which attempts to functionally link the fundamental components of the city so that the proceeding urban growth may occur in a controlled, compact, and sustainable manner. It is clear through the 'catalytic' approach that public transport is the key to effective and sustainable service delivery, i.e. balanced service delivery, as demonstrated by the case study of the planning and implementation of the Rivers Monorail in Port Harcourt, Nigeria.

INTRODUCTION

The current state of infrastructure service delivery – not only in South Africa – is not at the appropriate level where it can fulfil the growing urban needs of an ever increasing population. This imbalance can be contributed to the present urban dynamics which form a city/metropolitan structure that represents an unsustainable environment in terms of all spheres of society, be it natural, man-made, economical or institutional.

The following paper attempts to explain the probable forces and approaches that lead to the problem of imbalanced urban growth and the subsequent imbalanced service delivery. It then discusses a case study of Port Harcourt, Nigeria, where the implementation of a monorail is serving as a catalyst for more sustainable growth and service provision, thereby illustrating how public transport is the key to counter the problem of urban imbalances.

URBAN STRUCTURE DYNAMICS

Africa (including South Africa) presents significant levels of urbanisation due to the continuous population growth present within this developing continent. According to the UN-Habitat's State of African Cities report (2014), the total African population is projected to nearly double from around one billion in 2010 to almost two billion by 2040, with forecasts showing average densities increasing from 34 to 79 persons per square kilometre between 2010 and 2050.

Although the need obviously exists to plan for this growth, a compact urban structure cannot be obtained when the urban footprint continues to sprawl. Urban growth has overtaken the delivery and maintenance of engineering services, thus hindering the creation of safe and functional urban centres which attract investment – a necessary component for the development of cities.

The disrupted urban structure can be contributed to the present dynamics responsible for the following key characteristics as illustrated in Figure 1:

- A core area from where the city originated, which becomes densified and compact
- Main mobility routes that radiate from the core to the peripheral areas, along which densification and development occur
- Secondary nodes start to develop at strategic locations along these corridors
- The peripheral areas experience pressure in terms of development as land is cheaper there
- This leads to ad hoc developments which are not concentrated and encourages urban sprawl, all of which causes major problems in terms of service delivery
- Urban decay becomes the ultimate result of these dynamics, as ill serviced areas become desolate and obsolete in terms of social and economic value.

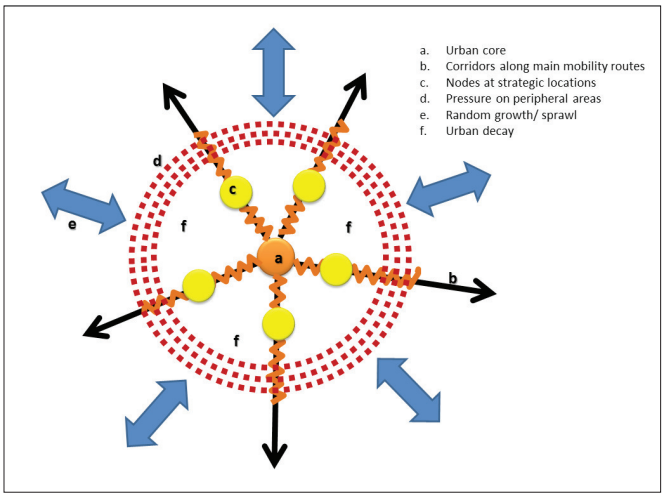

FIGURE 1 Present urban structure dynamics

There is a need to create an urban model which will maintain the functional elements of the city so as to encourage investment to stimulate effective urban growth and development. An example of a human body can be used to explain this urban model: Although all of the limbs in a human's body do not have to function, the necessary organs of a body must function and blood must flow for it to exist. Just like the human body, the urban body must also rely on the delivery and maintenance of its critical elements and efficient movement/mobility in order to sustain itself. Figure 2 illustrates the improved urban model.

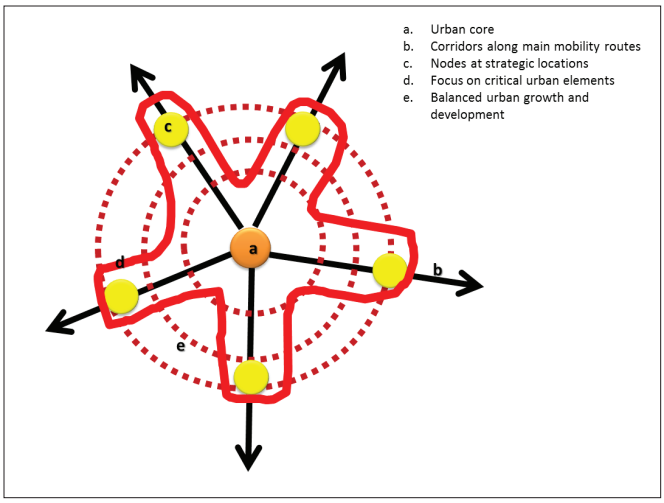

FIGURE 2 Improved urban model

By reviewing past tendencies in urban transformation, it seems that there are three approaches towards addressing the imbalance of service delivery: the 'do it all', 'backlog eradication', and 'catalytic' approaches.

The 'do it all' approach

This approach (illustrated in Figure 3) simulates business as usual and is based on the notion that the lack of services in the area/city/metropolis

must be dealt with in its entirety. It is similar to a 'band aid' approach whereby all the insufficiencies are attempted to be dealt with on a short term, quick fix basis. In this case, the demand for services overrides the supply thereof and leads to an overall process of urban degeneration as there is no specific focus on the critical elements ('vital organs') in the city and a lack of distinction exists between these critical and the other less critical areas/elements. The result is an unsustainable city with continued lacking service delivery.

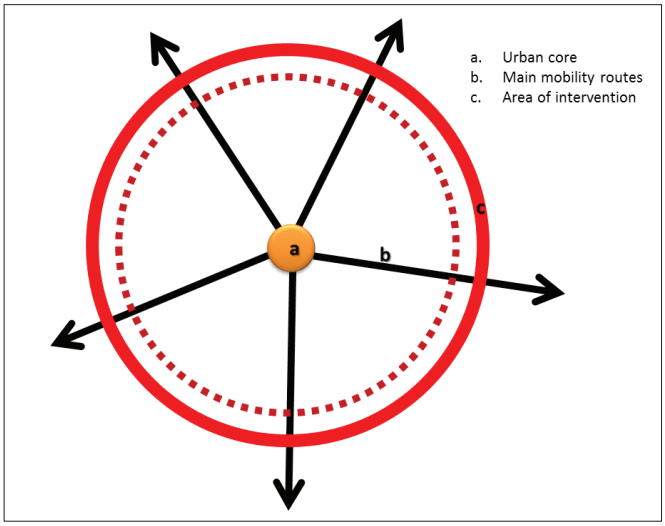

FIGURE 3 The 'do it all' approach

The 'backlog eradication' approach

This approach (illustrated in Figure 4) deals with service delivery by focusing on the eradication of historical backlogs. Although controversial, the trend is followed widely for political reliance, but again shows imbalanced service delivery that leads to unsustainable urban development and growth. This ineffective servicing of the 'urban body' leads to urban collapse as the focus is once again not on the critical urban elements.

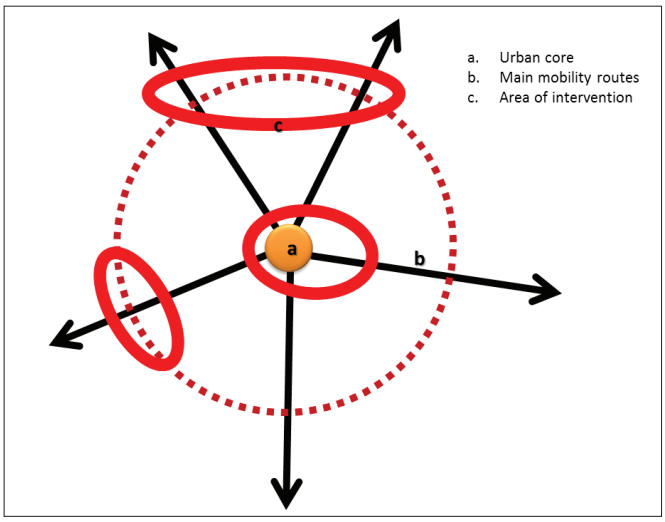

FIGURE 4 The 'backlog eradication' approach

The 'catalytic' approach

This is a balanced approach (illustrated in Figure 5) which attempts to functionally link the fundamental components of the city so that the proceeding urban growth may happen in a controlled, compact, and sustainable manner. The approach strives to link areas of opportunity with public transport systems, which allow for improved connectivity and accessibility, thereby also directing and providing for sustainable urban growth. The approach supports the 'urban body' by focusing on service delivery and maintenance in a controlled manner and therefore building an attractive investment core that leads to the 'improved urban modal' as previously mentioned.

The components of a functional and sustainable city structure (i.e. the 'improved urban modal') are clear: healthy cores/ nodes that are connected with efficient transportation links (including all modes of transportation) which are supported by appropriate residential densities – the key being public transportation and focused service delivery to create a balanced urban entirety.

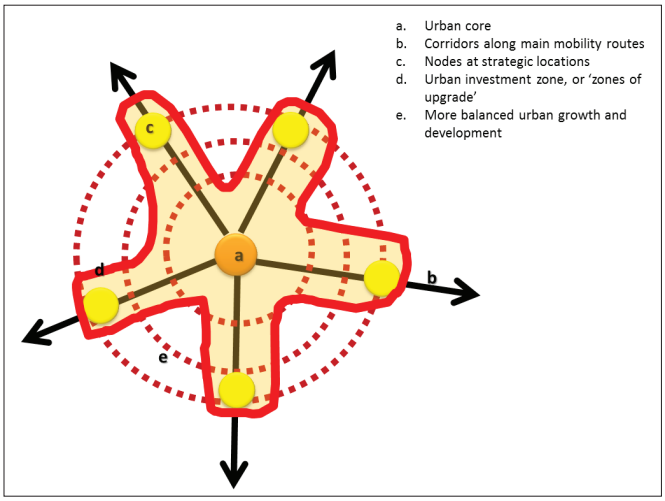

FIGURE 5 The 'catalytic' approach

It is clear through the 'catalytic' approach that public transport is the key to catalytic and sustainable service delivery, i.e. balanced service delivery. Balanced service delivery is therefore one of the aspects which systematically occurs when urban planning is integrated with transport planning and engineering services planning, as will be illustrated through the case study of the planning and implementation of the Rivers Monorail in Port Harcourt, Nigeria.

RIVERS MONORAIL – A CASE STUDY

There are several examples in African countries where the improved urban model is envisioned through proper planning and development, leading to balanced service delivery. In Harare the upgrading of the water system is being utilised as a catalyst for the redevelopment of the inner city. The development of a new rail link in Togo is seen as a catalyst to direct future urban growth and accompanying delivery of engineering services. The monorail in Port Harcourt, Nigeria serves as another example.

The reality of Port Harcourt

Port Harcourt is a bustling Nigerian city, struck by poverty, over-crowdedness, poor infrastructure and sub-standard service delivery (i.e. water, sewage, electricity, stormwater and waste removal). Urban growth has overtaken service delivery completely in the city, causing an unsustainable living environment as shown in Figure 6 and Figure 7. However, it is a city with locked up potential and a desire to return to its previous image of being the Garden State.

Relief for urban pressure gained from the monorail

The Rivers Monorail project injected a bout of potential development opportunities into the city when it was proposed that this mode of public transport be implemented to alleviate some of the traffic problems and

FIGURE 6 Congestion in Port Harcourt

FIGURE 7 Poor road infrastructure of Enugu/Port Harcourt Expressway

to connect the western side of the city to the city core. From the Sharks Park precinct in the south, to the Waterlines precinct in the north, the route provides for six monorail stations to be implemented in a two-phase approach. The route was chosen in such a manner that it will serve as a catalyst for city upliftment by increasing nodes and identity in the city; countering the notion of continuous sprawl; and improving the chaos and congestion on the existing road adjacent to the monorail route. Figure 7 illustrates the alignment and stations placement of the monorail, while Figure 8 and Figure 9 conceptualise the notion of 'zones of upgrade' at the Sharks Park station precinct.

Although the technicalities and engineering aspects of the monorail itself is of the utmost importance, the system will fail if not put in a spatial perspective that considers not only the beams, tracks and trains, but also the broader physical, social, economic and institutional environments. In this regard the monorail stations become pockets of improvement, whereby the necessary infrastructure upgrade and provision in and around the direct station area may lead to further investment with incentives to provide proper services in the adjacent areas, in which case the catalytic effect of the station precinct development can commence.

Catalytic advantages of the monorail

There are numerous advantages of the monorail as a catalyst for urban renewal: an improved movement system is possible which directly increases the mobility and connectivity of the city; functional, mixed land use, urban nodes can be created with a full array of engineering services to serve future investors; and aesthetically pleasing urban spaces can be

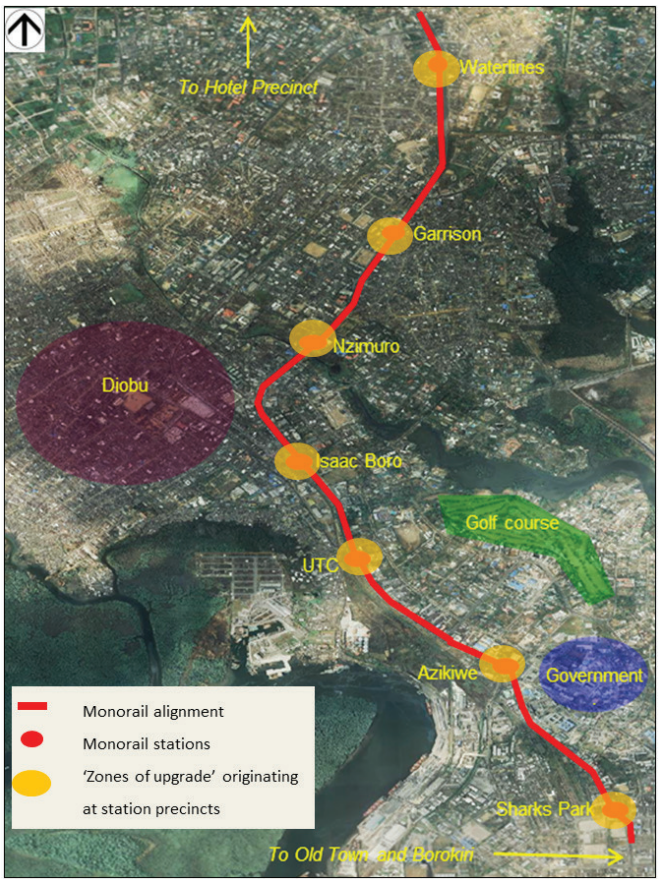

FIGURE 8 Monorail alignment and stations

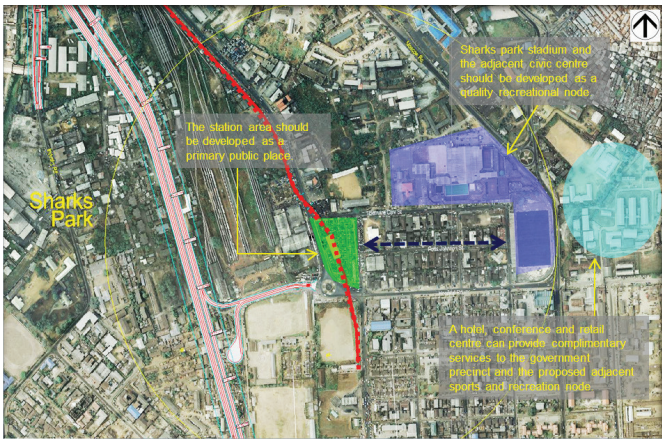

FIGURE 9 'Zone of upgrade' at Sharks Park station

created, instilling pride in the citizens of Port Harcourt. Figure 10 illustrates the concept of urban renewal through the catalytic rail station.

Therefore, the Rivers Monorail does not only provide the foundation for better mobility and connectivity within the city, but also for transit oriented developments around the station areas where services are explicitly planned for and incorporated into a master plan structure of the city.

It can already be seen in Port Harcourt how the implementation of an engineering project such as the Rivers Monorail, can lead to the improvement and upliftment of the broader community through strategically planning and developing the opportunities that the system has to offer, specifically the implementation of infrastructure and provision of services in and around areas that are now more capable of attracting business and social prospects.

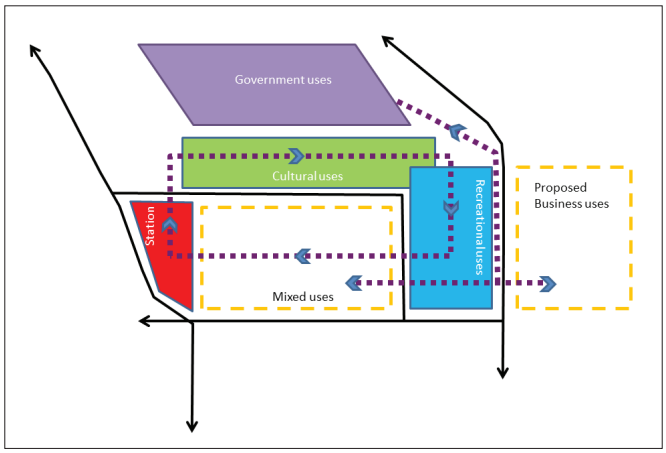

FIGURE 10 Vision for the Sharks Park station precinct

By utilising the monorail in this manner it will continue to contribute to achieving the 'improved urban model' as discussed earlier.

CONCLUSION

In conclusion, the 'catalytic' approach can lead to the 'improved urban model' which better meets the political requirements of today's democracy, and contributes to improved environmental conditions through the practical compaction of the city. From a financial point of view, funds are concentrated around the heartbeat of the city whereby the resulting investments are used to achieve sustainable transport systems. The subsequent urban form will also lead to the more effective and balanced delivery and maintenance of water, sanitation, power, stormwater and roads services.

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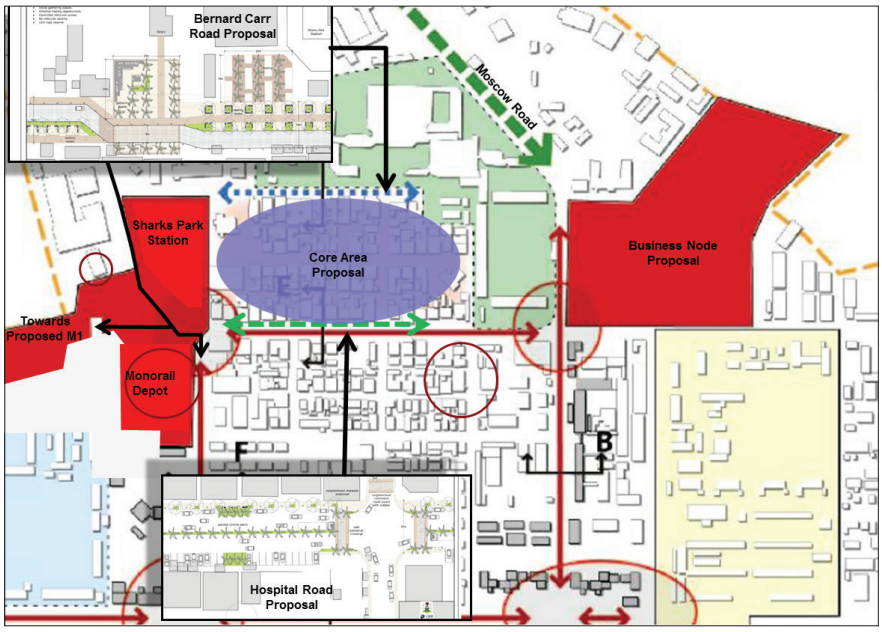

FIGURE 11 Catalytic effect of the monorail for urban renewal

THE BENEFITS OF MUNICIPAL TUNNELLING – THE MAHATMA GANDHI ROAD SEWER "NO-DIG" PROJECT

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ABSTRACT

Durban Harbour in South Africa is one of the busiest ports in Africa. The National Ports Authority needed to upgrade the port to accommodate larger ships. This required that the harbour mouth be widened and deepened. To pave the way for this modernisation of the harbour, a new and deeper 4.4 m diameter Durban Harbour Services Tunnel constructed using a "Mix-shield" slurry tunnel boring machine, the first in sub-Saharan Africa was built and commissioned in 2006.

The other developments in the area saw the emergence of a modern theme park "Ushaka Marine World" and the Durban Point Development Corporation (DPDC) up-market residential buildings. These developments contributed to a sharp rise in the value of land at the Durban Point Area. To pave the way for the future expansion of the point Area for residential development, Mahatma Gandhi Road sewage pump station would require to be relocated and the incoming gravity sewer extended by 223 m. The close proximity of protected buildings dictated that the sewer extension negotiate a difficult radius before entering the reception shaft, in the Durban Harbour Tunnel launch shaft. This paper will focus mainly on the gravity sewer extension portion of the project.

INTRODUCTION

The Early History of Municipal Service Delivery Tunnelling in Southern Africa: The first water tunnel built in Southern Africa was the Woodhead Tunnel in Cape Town – it was 360 m long and its 1.7 m diameter allowed for water to be conveyed from Table Mountain to Camps Bay. Due to its growing population the Durban Corporation's water supply pipeline from the Umlaas intake to the Umlaas filters had to be built consisting of 5 tunnels totally 2.2 km in length. Today KwaZulu Natal boasts some 58 water supply tunnels totalling 79.5 km in length and 20 sewer tunnels totalling 8.3 km. Typical examples of the benefits of tunnelling in a Municipal environment together with examples of challenges faced such as asset management and maintenance will be illustrated in the presentation.

The South African National Council on Tunnelling (SANCOT): SANCOT was formed in 1973 and was a founding member of the International Tunnelling Association (ITA). Working groups within SANCOT include subjects such as "Shotcrete Specification" and "Tunnel O&M and Asset Management". Some years ago a detailed "Database of Tunnels in Southern Africa" was compiled and SANCOT is presently digitising and updating this document which will be freely available once completed. From this database it was interesting to note the statistics reflected in the document, the number of Tunnels in Southern Africa by category:

Dam related	48
Electricity Cable	6
Access and Special	39
Hydro power	8
Railway	219
Road	43
Sewer	52
Water	146
TOTAL	**561**

Durban's Sub-Aqueous Tunnel: Prior to 1966 the City's effluent was merely discharged into the harbour entrance at high tide. A pre-cast tunnel used to convey the effluent to the Central Waste Water Treatment Works was laid on the sea bed and had to be replaced recently with a longer and deeper tunnel using a 4.6m diameter TBM.

PROJECT BACKGROUND

As one drives down Mahatma Gandhi Road (formerly Point Road) at the Point Area of the City of Durban one would be aware of the odours from the sewage pumpstation, built some 50 years ago.

On the left hand side of the road is the Transnet (National Ports Authority) yard and on the right is a line of protected historical buildings and further on and around the existing sewage pumpstation are a number of "up-market" apartment buildings developed by the Durban Point Development Corporation (DPDC). See Figure 1.

FIGURE 1 Durban Harbour mouth showing harbour tunnel and widening of entrance channel

In order to free this valuable land occupied by the existing pump station, eThekwini Water and Sanitation (EWS) were requested to relocate the sewage pump station located along the Mahatma Gandhi Road. A new home for the pump station was found adjacent to the Durban Harbour Tunnel, some 225 m from the current location. See Figure 2.

To fulfil this objective, eThekwini Water and Sanitation appointed Hatch Goba to design and manage construction of the new, relocated pump station and decommission the existing pump station. The new works are located adjacent to the newly expanded and deepened Durban Harbour mouth. The new works comprise 223 m sewer gravity extension under the Mahatma Gandhi Road, new underground pump station and further rising main connections into the Durban Harbour Tunnel. See Figure 3.

The new pump station was constructed underground, comprising a pump station dry well/wet well configuration, a screening chamber and a state-of-the-art odour control system. This relocation meant extending the sewer by 223 m, following the alignment of the Mahatma Gandhi Road, which is criss-crossed by numerous buried services. Along the relocation alignment, there were sensitive, protected buildings. Due to these, combined with the ground conditions (saturated sands), sensitive services and to minimise disruption to "Third party" and businesses in the area, a No-Dig installation method was the most suitable for sewer extension.

GEOTECHNICAL SETTING

The site was located at the mouth of the Durban Harbour in an area previously occupied by the mouth of the natural estuary of the rivers draining into the south Durban basin, and prior to that by the mouth of the

FIGURE 2 Point Area setting

Umgeni River. A total of five boreholes were drilled along the sewer extension alignment. Extending from ground level to depths ranging from 1.0 to 2.0 m is a layer of fill material which comprises the road layerworks.

Underlying this are marine sands, slightly gravelly sands and gravelly sands that are almost indistinguishable from the insitu sands below.

Underlying the surface fill horizon was a consistent layer of light brown to brown, generally medium dense to very dense, fine to medium grained sands up to a depth of 5.0 m, with occasional layers of silty to clayey sands below 5.0 m depth. In some areas the sands become medium coarse-grained and contain shell fragments.

Holocene marine sands, which extend to depths in excess of 10 m, typically comprise a poorly graded fine to medium grained sand with a minimal amount of fines.

Measurements using a standard dip-meter, showed groundwater levels of approximately 2.5 m below the road level. Permeability test results based on pump tests carried out during the investigation indicate that the in situ permeability ('k'), of the sandy materials underlying the proposed pipeline route ranges between 5.16 x 10-2 and 5.8 x 10-1 cm/s. See Figure 3.

DESIGN CONSIDERATIONS

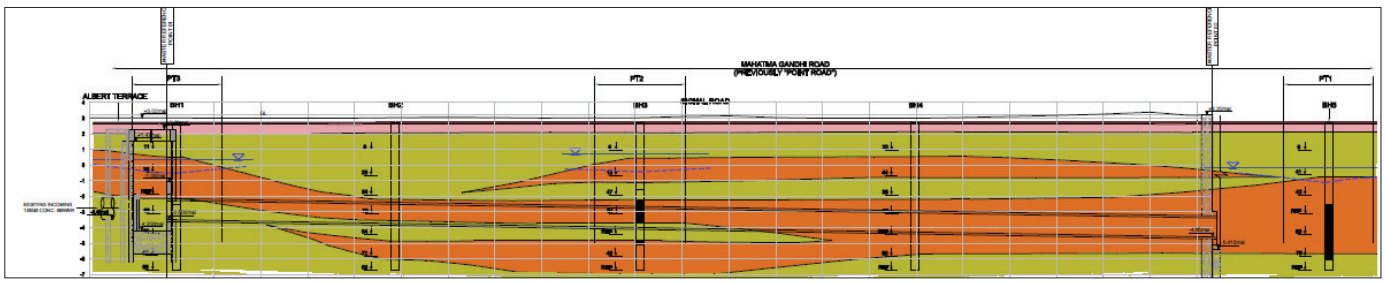
The objective of the initial study was to evaluate the various sewer pipe extension installation techniques available by taking technical, financial and social-environmental aspects into consideration upon which the selection of the method would be based. Some of the objectives of the study were, inter alia:

- Investigate installation options within the constraints of the site and alignment;
- Investigate known construction risks and implications thereof;
- Provide the suitable recommendations based on the conditions.

The Mahatma Gandhi Road is criss-crossed with numerous services, new and old, some are abandoned. Every time the area was excavated, new services were uncovered, which makes it dangerous for construction personnel and equipment. Some of the services here include fibre optic cables and power and communication lines for the National Port Authority (NPA). Disruption to these services was not an option and relocation thereof was quoted in the order of millions of Rands per linear metre of cable. See Figure 4. That made the option of open-trench method of pipe installation unfavourable.

In terms of technical and financial considerations, aspects such as direct and indirect financial implications were investigated. Some of the indirect implications are:

FIGURE 3 Geological Section



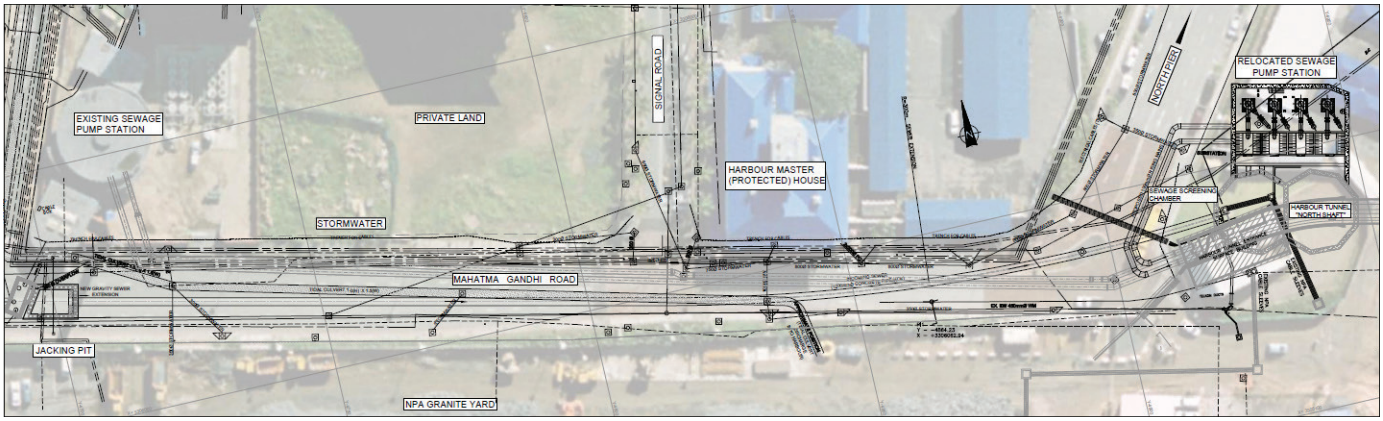


FIGURE 4 Services Along the Alignment of Sewer extension

- Disruption to traffic could cause the businesses in the area to lose up to 50% of their revenues
- Digging and repairing could reduce a road design life by up to 20%
- Cost of relocating of non-NPA fibre optic cables could cost in the order of few millions of Rands and could also potentially disrupt the port operations.
- Disruption to traffic on Mahatma Gandhi Road, a major urban road servicing the Durban Point Precinct
- Ground settlement associated with construction methods involving lowering of the groundwater table or loss of implementation of ground stabilisation can cause significant and costly damage to some of these services and roadworks
- Potential damage to the historical buildings on the north side of the road as result of ground settlement
- The structural integrity of the 50 year old underground chamber adjacent to the existing pump station.
- Tight tolerance for breaking-through into the existing Harbour Tunnel shaft's heavily reinforced walls and treatment of the ground behind the "piercing location" where the shaft wall was cut
- Curved sewer extension installation to avoid foundations of the historical buildings. Most of the microtunnelling with curved alignments almost always gone wrong
- Cost and availability of the equipment were viewed as additional constraints for the project.

SOCIO-ECONOMIC INPACTS

The following considerations were addressed during the study:

- **Economic Issues:** The detailed impact of the preferred method and potential risks/fatal flaws associated with the project, were determined including economic implications. There were few businesses around the project area, including the entrance to the harbour mouth. A detailed economic impact was undertaken for the selected installation methods, including engaging affected third parties to ensure a smooth and successful project.
- **Geotechnical Issues:** Further ground investigations were undertaken along the pipe extension route. Several onsite and laboratory tests were conducted to confirm the ground conditions and their geotechnical properties. The water table levels, groutability of the sands and the frictional resistance between the pipe and soil mass (skin friction) were determined for the design and construction. The records indicate that a lack of information on ground conditions could lead to the encountering of potentially costly, unknown construction hazards.
- **Environmental Issues:** It was established that the use cementitious grouting to stabilise ground would likely cause some contamination of groundwater. In sandy soils, grout generally tends to follow path of least resistance, which could end up undesirable places. However, this was not expected to be a major concern in the project area, due to proximity of the harbour channel. The other major environmental impact and concerns would emanate from material excavation, haulage and disposal; mess caused by open-trench installation method.
- **Sociological Issues:** The single most significant sociological impact identified at the time would emanate from disruption of road traffic, which in turn would cause disruption to businesses, during the construction of the connection chamber or during trench excavation in the case of open-trench method. The other indirect disruption could be caused by disruption of utilities serving businesses and communities. The impact these cannot be quantified during the study. The constraints and the available technology (together with environmental and economic aspects), were used for the determination of the most favourable sewer pipe extension installation method.

INSTALLATION OPTIONS

Various construction methods for the sewer extension were investigated, such options as "open-trench", "conventional/traditional pipe jacking" with dewatering or ground improvement, "Horizontal Directional Drilling" (HDD) and "Microtunnelling" were considered. Their advantages and disadvantages were compared. See Table 1 below. The options are listed below:

- Microtunnelling
- Pipe Jacking
- Horizontal Directional Drilling (HDD)
- Open-Trench
- Pipe Ramming.

The report highlighted the merits and demerits of individual sewer installation methods. Each method was evaluated in detail including the evaluation of cost and socio-economic impacts and benefits. The complexity of the project required a thorough determination and examination of all risks, pros and cons. Many of the risks have been identified and discussed above. All options were assessed for "potentially fatal flaws" and the identification of such flaws relating to individual options were summarised in the table below. In essence, all of the options were technically viable – but clearly with varying degrees of construction hazards, the delimitation of which were mostly related to the project capital cost. The options evaluation and subsequent conclusions were summarised as follows:

- **Pipe Ramming:** a simple to use method, but "cons" outweigh the "pros", as indicated in the summary table below. In short, the method is suitable for jacking up to 100 m lines. Longer jacking distances require intervention shafts or intermediate jacking stations. In addition, the sandy soils would almost certainly require ground stabilisation and the potential presence of obstructions would likely to cause pipe to bend. All the above issues made this option unfavourable.
- **Open Trench:** most widely used and accepted method in South Africa. Whilst its use in the First World has fallen to near-zero in urban areas

Element	Horizontal Directional Drilling	Pipe Jacking	Microtunnelling	Open-Cut Trench
Design Issues	• 2No. pipes will be required due to size limitation • Poor control and alignment will require steeper grade (greater than 1:100) • Steeper grade will cause pipe invert to be below north shaft base plug • Deeper pumpstation sump is likely • Less strong pipes required for installation • Not suitable for gravity sewer installations	• Ground stabilisation ahead of the jacking face using cementitious grout has no local track record • Other ground stabilisation methods (ground freezing, etc.) to be explored to avoid water table lowering (likely to cause ground settlement effects) • High strength pipes required for installation to withstand the jacking forces. 'Ground loading on pipe is therefore less onerous • Suitable for gravity sewer installations	• Shallow gradient can be used, appropriate to sewer installation and larger diameter. Useful for peak flow buffering • No water table lowering or ground stabilisation required • Higher strength pipes required for installation to withstand the jacking forces. Ground load is less onerous • Precise machine alignment control 'from the surface' makes this method ideal for gravity sewer installations	• Pipes require only to withstand ground loading • Method is suitable for gravity sewer installations
Geology	• Ideal for self-supporting ground • Can be used in sandy conditions below water table which may call for ground stabilisation (bentonite drilling fluid) • Not suitable where obstructions are likely to be encountered	• Ideal for self-supporting ground • Not suitable for sandy conditions below water table (requires ground stabilisation)	• Most suitable method for cohesionless soils below groundwater conditions	• Traditional sheet piles may not be suitable for soft ground below water table, where obstructions may be encountered • Ground material washout is a potential hazard (likely to cause ground settlement)
Groundwater	• Water table lowering not required for this method	• Requires extensive water table lowering and dewatering throughout excavation and pipe installation, which is contra-indicated on potential ground settlement basis	• Most suitable method for high water table conditions • Not necessary to lower water table	• Potential surface settlements due to lowering of water table
Effects on Third Party	• Disruption of traffic along Mahatma Gandhi Road (at machine setup point and plus connection chamber) • Regular check pits to drill head alignment checks	• Water table lowering option may lead to significant surface settlement or sinkholes • Hence potential damage to existing utilities and adjacent protected buildings	• Minimum surface settlement can be expected • Limited traffic disruption along Mahatma Gandhi Road	• Surface settlement (if not ruled out by ensuring no lowering of water table) likely to damage third party utilities • Open excavation can be done only on alignment, adjacent to NPA granite yard • Significant traffic disruption over the longer length of Mahatma Gandhi Road
Environmental Considerations	• Less containment of slurry	• Environmental concerns in respect of cement/bentonite grouting for ground stabilisation, ahead of excavation face (though passage of grout a distance away from face can be avoided by using grout blobs	• Potential ground water contamination from machine slurry pressurisation	• Large amount of material handled during excavations and backfilling of trench • Increased heavy haulage traffic thus increasing carbon emissions
Economic Considerations	• Cheapest method. It is also locally readily available • Excavation for check pits in the middle of the road and around the services may increase the overall cost	• Relatively expensive option, but cheaper than microtunnelling • Ground stabilisation may become very time consuming and therefore costly in the long term	• The higher up-front cost may be offset by relatively short time of excavation	• Relatively cheap method, but the limited drive length capability may dictate that additional jacking pits may be excavated (a costly exercise) • Method was not considered much further
Construction Considerations	• Larger establishment area will be required • Limited size of pipe can be installed (up to 900 mm diameter) • Potentially poor control of alignment, particularly below water table, makes this option not ideal for gravity sewer installations • Drilling would have to start some 100 m back to align drill rod with design pipe grade at connection chamber (at 6 m below ground level) • Have to bypass the existing chamber, requiring dog-leg connection • Any obstruction or hard strata can cause deviation from design alignment • The major risk is associated with hard strata or obstruction that might bring the drill to a complete halt • Will require watch pits/manholes along the route to confirm and control levels	• Require ground stabilisations ahead of the jacking face to allow man entry for proposed hand excavation • Requires continuous dewatering at the face • Can advance/excavate only within stabilised ground. • Precise control and alignment, which is suitable for gravity sewers • Compact site establishment	• Ideal for use in most ground conditions • Precise control and alignment, which is suitable for gravity sewers • Jacking from existing DHT north shaft • Reception pit 4 m x 5 m in Mahatma Gandhi Rd • Compact site establishment • Site establishment required to accommodate slurry plant, operator control room, pipe storage hoisting crane, etc	• Relocation of services to make space for sheet piles • Avoid severing some utilities with sheet piles • Require shoring due to depth • Hard obstructions can cause sheet vertical joints to open and subsequent major leaks/mud rush • Continuous dewatering required at bottom of the trench • Some pipe jacking will still be required with this option (under the new recently installed sewer mains, for connection into the DHT north shaft)

Health and Safety	• No personnel access required, except in the "jacking/reception" pits and connection chamber • No major H&S concerns for this method	• Requires man-entry for manual excavation (1500 mm not suitable for personnel entry) • Potential sand/mud-rush if ground treatment not successful	• No personnel access required, except in the jacking/reception pits and during interventions	• Space confinement and only narrow trench can be excavated due presence of utilities • Access to the bottom of 6 m deep narrow trench and risk of local failure on trench sidewalls
Construction Programme	• Need to drill 2No. bores may be time consuming	• Excavation advance dependent on success of grout injection • Achievable advance rates of 2 m and 1 m per days for "best" and "average" respectively		
Operations Considerations	• Possible to put one of the installed lines 'offline' for operations without disruption of sewage flows			
Cost Implications	• Low upfront cost in comparison with other options	• Technology readily available in the country, therefore less cost	• Technology is non-existent in RSA (although common method overseas). High upfront cost due to import of highly specialised tunnel boring equipment and expertise • Cost-effective due to shorter construction durations	• Large amount of material handled during excavations and backfilling of trench • Increased heavy haulage traffic for transporting of excavated and backfill material
Other Advantages	• If inaccuracy of this method realised, then degree of long term interference with access along the road will be minimal			
Other Disadvantages	• Case studies of HDD installed gravity sewers do not exist. Hence this method will be a prototype • The method needs bigger space to lay out the pipe string before it is pulled into final position	• Uncommon method for installation in soft ground, below water table	• Limited (or no) contractors with the microtunnelling equipment and expertise in SA	• Potentially hazardous for construction and local buildings, unless water table lowering is avoided

TABLE 1 Summary and Comparison of Installation Options

for obvious reasons. Although still used in build-up areas and city centres, it is generally ideal for shallow, countryside projects. In deep pipe installations (6 m deep in the case of Mahatma Gandhi Road Project) and soft ground, the trench sidewalls would generally require sheet-piles and props support on sidewalls. Numerous services criss-crossing the road would also prove this method very difficult, unless the service were relocated or trench was dug in the "third party's" land (NPA granite yard). Dewatering of the trench would cause potentially a degree of ground settlement. The other factor making the method unfavourable was the socio-economic impact (extended disruption of traffic, likely disruption of services and local businesses, indirect costs associated with cutting and repair of the road surface, etc.). The Open trench method was therefore disqualified on the basis of this endless list of risks and disadvantages.

- **Horizontal Directional Drilling (HDD):** relatively cheap in comparison with pipe jacking and microtunnelling. The HDD has limited drilling capacity in terms of pipe diameter (maximum 900 mm); therefore in order to compensate for (or to match) the incoming sewer pipe size, two bores would have been required. One on the most difficult items of the HDD would be to control and hold a constant grade of the drilled pilot hole and to maintain the alignment of the drill head and reamer, which made it not a very popular method for installation of gravity sewer mains. Hence steeper grades exceeding 1:100, are preferred when using this method. The consequence of this "necessity for very steep grades" is the effect it has upon the depth of the proposed sewage pump station sump in which the sewer pipe would discharge. To overcome the problem of alignment control, watch pits/manholes would be dug along the route to expose the drill head and confirm the levels or adjust as necessary. Digging these watch pits within the busy, services criss-crossed Mahatma Gandhi road would not have been an easy and cheap task. As a consequence of above arguments, the method was not very favourable for the project.
- **Pipe Jacking:** favourable method for sewer pipe installations for short drives. The cost estimate, availability of expertise and technological application (suitability for sewer pipe installations) made this option very attractive. This method is normally suitable for used in all ground conditions but in saturated dense sands (below water table). Stabilisation of ground (in soft soils below water table) would be a prerequisite for the safety of personnel and equipment and also to minimise potential ground settlement due to volume losses. Of all the considered ground stabilisations methods (dewatering, bentonite/cement grouting and ground freezing), none seem to be flawless, particularly when there was no track-record of use in similar circumstances. The risk of these methods proving unsuccessful on-site was appreciable. The selected process would take a long time to attain 100% effectiveness and as a consequence could be very costly.
- **Microtunnelling** has the highest cost and the lowest risk rating of the options considered. Without much detailed analysis of options, It was established that the shorter excavation duration, in comparison with other options, this would compensate for higher upfront cost in the long-term and would make this option more comparable/ competitive or even more attractive than the second-best (pipe jacking method), in terms of cost.

On the bases of analyses and arguments discussed above and the analogy summarised in the comparison table (see Table 1), it was concluded that the microtunnelling option was the most suitable sewer installation method for the Mahatma Gandhi Road Sewage Pump Station incoming gravity sewer extension and having least negative impact on the known constraints.

ALIGNMENT OPTIMISATION

As areas increase in density, space becomes cluttered with supply lines. One way to accommodate the growing demand for conduits and services, including sewer lines, would be to place them in tunnels freed from the general plans on the surface. This was typical along the Mahatma

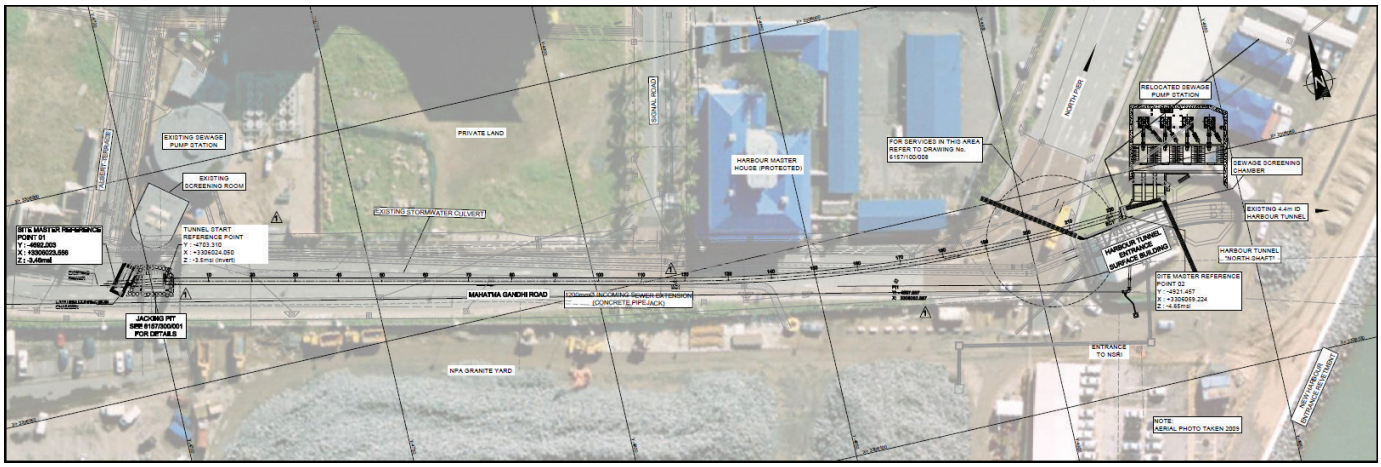


FIGURE 5 Alignment of Microtunnel Sewer extension

FIGURE 5A Alignment of Microtunnel on the surface

Gandhi Road and the Point Area in general. The sewer pipe extension alignment had to be curved to avoid tunnelling under the protected, historical "Harbour Master's building". This made it challenging to designing and choosing suitable installation method and equipment. Such curved microtunnels are apparently very difficult to negotiate, particularly if the alignment control was critical, such as in flat grade sewers. In the Mahatma Gandhi Road case, the break-in to the pre-opened existing reception shaft had to be very accurate, within a few millimetres of accuracy. Deviation from line meant that the machine would drill in the heavily steel reinforced concrete wall.

To negotiate the curve, an experienced operator had to carefully work the sensitive steering rams in the machine, ensuring the desired angle was maintained to avoid overstressing the jacking concrete pipe, by way of inducing point load on the concrete pipe and also maintaining the alignment. See Figure 5 and Figure 5a.

The Tunnel Length was approximately 225 m, consisting of:

- 115 m Straight section from the jacking pit
- 105 m arc length with 350 m radius, curved section to bypass the protected historical, Harbour Master House
- 5 m Straight section, breaking into existing Harbour Tunnel north shaft

JACKING PIPE DESIGN

The ground conditions dictated that only a closed face, pressurised slurry type MicroTBM was used for pipe installation. Due to the Length of the tunnel being in excess of the desired length for the conventional hydraulic drive from container to machine, Herrenknecht AVN-2000TC type machine, owned by Coleman Tunnelling (Ireland) was used. The type "AVN 1200TC". See Figure 6.

The Client required that due to difficult construction conditions, restricted access to the sewer-line and the importance of the sewer system,

FIGURE 6 MicroTBM before launch

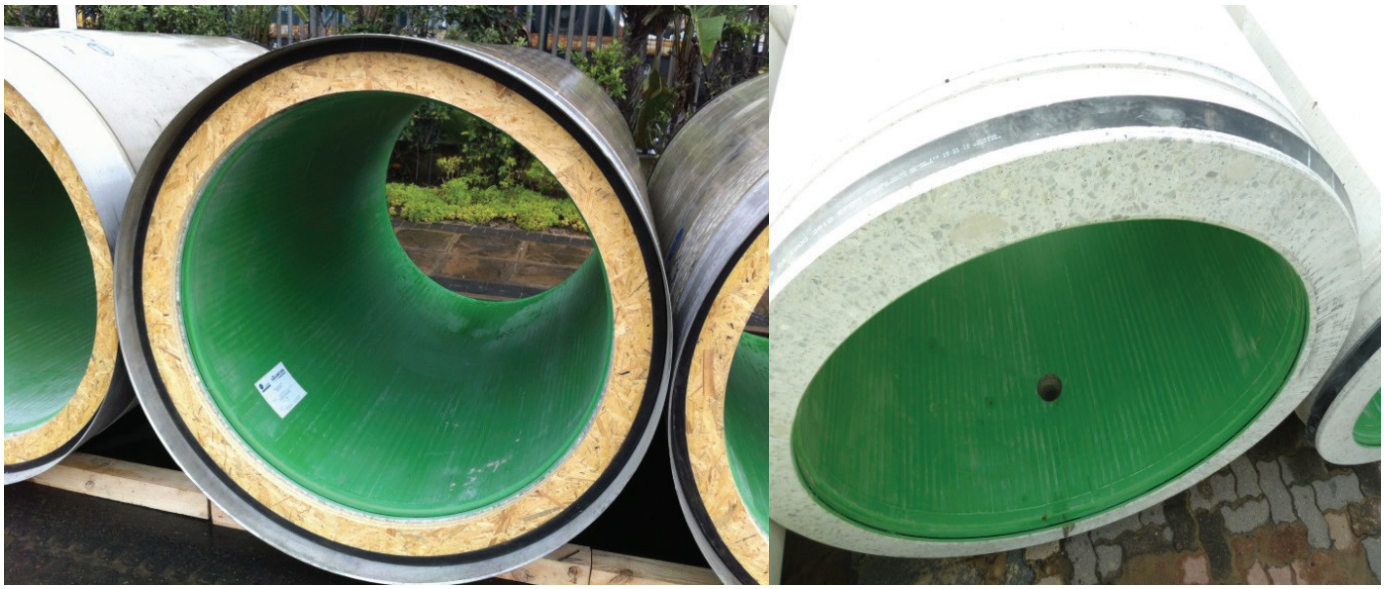


FIGURE 7 HDPE lined Concrete Jacking Pipes

FIGURE 8 MicroTM and Pipe Installation in the Jacking Pit

the 1200 mm internal diameter concrete pipe was to be designed for a 100-year life span. The reinforced, 145 mm wall thickness concrete pipes with characteristic strength of 40 MPa were designed, taking into consideration the known fact that the Durban marine environment is highly corrosive. This, combined with the fact that the concrete sewer pipe would be below the saline groundwater table and corrosive nature of sewage, required high durability concrete to be specified. Although the extrados of the pipe will be permanently submerged, measures had to be put into place to minimise material attack by salt water. These materials included duplex stainless steel collars and rubber seals for pipe joints. A special grade (AISI 32507) stainless steel was used for its resistance to pitting corrosion. To eliminate chemical (sewage gases and hydrogen sulphide) attack to the concrete, the pipe intrados was lined with 'cast-in', continuously welded HDPE. These considerations and protection measures will enhance material durability to achieve the intended 100-year design life and beyond. See Figure 7.

EMERGENCY PREPAREDNESS

A contingency rescue shaft was allowed for in the "unlikely event" that the MTBM encountered an obstruction, such as old ship anchors or timber piles and stoppage of the tunnelling operations. In that case the position of the machine head and all known services would be marked on the surface. Various available options were investigated, including sinking a cassion shaft in front of the machine head to recover the MTBM or remove the object from in front of the machine so as to allow the tunnelling to re-commence. Whilst the obstruction was being removed, bentonite would continuously be pumped around the pipes to limit potential ground settlements.

CONCLUSIONS

The sewer extension line would be tunnelled rather than open-trenched due to the fact that there was less disruption to traffic and urban facilities networks of buried services/installations. The other advantage being that it traversed the area without major concerns regarding ground settlement, which could affect the integrity of or cause damage to the existing protected historical buildings.

The Mahatma Gandhi Road sewer extension Micro-tunnelled pipejack was the first use of a slurry machine and the first to do a curved alignment in Sub-Saharan Africa. This machine demonstrated the capability of technology to overcome the challenges of tunnelling through difficult ground conditions and negotiating curves and achieving tight tolerances. According to the records, this was one of the most successful curved microtunnel projects in the world. During the initial micro-tunnelling, minor subsidence was experienced. This was during the learning curve

and the Contractor was able to remedy the situation before reaching the sensitive structures. Although this lead to some delay while waiting for suitable slurry and lubrication material, microtunnelling was completed successfully. Completion of the tunnel means that the valuable land in the Point Area will be able to be freed for further developments.

The successful completion of this project demonstrated that the microtunnelling technology can be relied on and should be considered for implementation of pipelines and services in the cities, where space restrictions and disruptions to traffic, businesses and livelihood are a concern.

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