Kolkata's brick sewer renewal: history, challenges and benefits

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Many large-diameter brick sewers were built in central Calcutta (now Kolkata), India during the 1870s. However, over the past century they have deteriorated due to age, changed land-use patterns, lack of adequate maintenance and failure of limited past measures to upgrade them. In 2007, the Kolkata Municipal Corporation embarked on a major project of refurbishing the most critical stretches of these man-entry brick sewers with an estimated initial cost of £70 million. The first phase of this work is due for completion in 2014. A cost–benefit analysis shows an economic internal rate of return of over 15%, amply justifying the investment towards sustainable renewal of an indispensable infrastructure component.

1. Historical background

The birth of Kolkata (formerly Calcutta) as a commercial centre was initiated by Job Charnock (1630–1692) of the English East India Company in 1690. It became a ‘crowning glory’ of British rule and served as the administrative capital of continental India from 1757 to 1911. Planning and development of sanitation and drainage infrastructure for Kolkata dates back to 1803 when governor-general Lord Wellesley (1797–1805) stressed the need for public drains and watercourses for a city receiving over 1600 mm annual rainfall, mostly spread over a defined monsoon period (June to September).

However, despite several important instructions issued by the governor-general, the work of providing a drainage system had been limited to construction of Beliaghata Canal (1810) and a survey of the town undertaken by John Schach (1793–1825) (Smith, 1869). In 1821, Schach suggested providing major brick masonry sewers from the River Hooghly to the proposed circular canal for conveying both sewage and storm water run-off ultimately to salt-water lakes in the eastern part of the city (present-day Salt Lake City). By 1835, several drainage proposals were formulated by a number of prominent individuals (Goode, 1916).

1.1 The town scheme

Finally, a scheme proposal by William Clark, MICE (1821–1880) was submitted to the municipal commissioners in November 1855 and forwarded to the local government for approval. In 1858, it was decided by the government that the scheme proposals be reviewed by Alexander

Rendel (1829–1918), who later became consulting engineer to the Indian government and president of the Institution of Civil Engineers in London. On reviewing Clark's exhaustive response to Rendel's proposals, the commissioners finally sanctioned Clark's scheme in 1859.

Clark's scheme – known as the ‘town scheme’ – was conceived to serve as a combined system along the natural slope of the terrain away from River Hooghly and towards the salt lakes, from west to east (Goode, 1916). Under the original scheme, five main sewers were initially planned to be laid along prominent roads with their branch sewers, associated works and outfalls (Figure 1).

Two main intercepting sewers were to be constructed: one along Upper Circular Road (now APC Roy Road) from Sova Bazaar Street to Dharrumtollah (Moulali) junction, where it was to be joined with another one along Lower Circular Road (now AJC Bose Road) coming from Zeerut Bridge near Tolly's Nallah to Moulali junction. Three other main sewers were planned from the River Hooghly to open into the APC Roy Road sewer along Nimtala Ghat Street, Kolutola Street and Dharrumtollah Street (now Lenin Sarani). A main outfall sewer (the ‘Town Outfall’) was to convey this combined flow to Palmer's Bridge pumping station.

The total catchment area of the scheme was 19.1 km² and anticipated sewage flow at the pumping station was 1.27 m³/s from a contributing population of about 500 000. To induce self-cleansing velocity, arrangements were made to allow entry of tidal water into the sewers. The pumping station at Palmer's Bridge was deemed necessary to lift and convey the combined flow into a high-level sewer that would

eventually dispose of it at Tangra Creek, 3.2 km away. Its approval effectively dropped one of the modifications suggested by Rendel of joining the sewers by matching their soffits instead of invert – this remains a serious defect in Kolkata's brick sewers (Goode, 1916).

Construction of the Lenin Sarani sewer was taken up first, along with its downstream works including the pumping station, to evaluate the philosophy of the proposals. This part of the system was commissioned in 1868. A special committee then reviewed the benefits of the initial works and decided to complete the whole town scheme as originally proposed. Its construction was completed in 1885–1886, and by 1890 branches and laterals of around 177 km were added to the existing sanitation infrastructure.

1.2 The suburban system

Work on the 'suburban system' serving the southern part of the city was taken up in the late nineteenth century. Two main sewers constituted the suburban drainage system.

The first main sewer started from Kidderpore Docks, continued along Judges Court Road (in Alipore) after crossing Mominpur area, and crossed Tolly's Nallah by a siphon arrangement. Emerging on the eastern side, it continued along Hazra Road and culminated at Ballygange drainage pumping station. A second sewer was installed along Rashbehari Avenue that also terminated at Ballygange pumping station. This was followed by the supplementary 'Manicktala' and 'Tollygunge' systems. A number of canals in and around the city area also served as intermediate outfall points. The last system constructed in the city area was 'Tangra–Topsia' system.

1.3 Current situation

In total, there are now about 180 km of brick sewers in Kolkata. Of these, about 88 km are 'man-entry' sewers – that is sewers above 1.07 m (42 in.) diameter. Kolkata's wastewater and storm-water flow is pumped to dry-weather flow and storm-water flow channels respectively. These channels gravitate into Kulti River almost 36 km away from the city.

The underground sewer system was dimensioned for carrying storm water, which still constitutes the bulk of the combined flow. It was designed for a 2 month storm frequency. However, the sewers were designed for a much lower population concentration and significantly lower paved area than they are now subjected to.

Kolkata has experienced a major influx and growth of population over the past decades due to political events and evolving social and economic changes. The drainage scenario has also worsened due to loss of retention ponds, storm-water reservoirs and open areas being converted into paved surfaces to accommodate the additional population. The central area has thus started suffering from severe flooding.

2. Rehabilitation project

To formulate a workable and balanced refurbishment plan for the brick sewers, it was important to recognise and identify the problems with the existing sanitation system. Kolkata Municipal Corporation (KMC) had conducted several studies to assess the ground condition of its ailing sanitation infrastructure; the most important of these being the ones funded by the Asian Development Bank (1999–2000) and the World Bank (2000–2001).

These reports revealed the extremely dilapidated condition of the century-old brick sewers and the high level of siltation that could be

Figure 1. Layout of the five major brick sewers in Kolkata's central 'town system', which was completed to a British design in 1886 – all have now been cleaned and relined. Town Outfall has yet to be rehabilitated. Map source: CMS (1862)

Clark's scheme – known as the 'town scheme' – was conceived to serve as a combined system along the natural slope of the terrain away from River Hooghly and towards the salt lakes, from west to east

Figure 2. Over 50 000 m³ of silt had to be removed from the 26 km of brick sewers – much of which had solidified into rock-like material

Figure 3. Utilities cutting across brick sewer soffits have caused many of the structural failures, with almost five collapses a week occurring in 2006

correlated to sewer collapses and frequent flooding, respectively. The corporation thus drew up an urgent rehabilitation plan in 2006, designed to restore the hydraulic capacity and structural integrity of the sewers.

The absence of screening for flow entering the sewers, indiscriminate dumping of solid waste, lack of public awareness and the very limited and localised sewer maintenance work were the main causes of siltation and deterioration. The amount of silt and debris deposited in sewers was found to be very high and to affect severely their serviceability (Figure 2).

Reports also indicated degeneration of bricks and eroded mortar, causing structural distress and failure in several places. Sewers had collapsed in various locations at different times on account open of increased traffic over the roads, too. Exposing brick sewers by open excavation for the purpose of laying other utility lines also caused structural failure of sewers (Figure 3). An indication of the level of siltation in individual sewers, together with a statistical record of collapses from 1980 to 2006, is given in Table 1. Collapses reached an alarming level of almost five per week in 2006.

Name of system	Basin area: km ²	Brick sewer alignments along road ^a	Length: m	Maximum dimension: m ^b		Total collapses (1980–2006)	Duration of traffic blockage: h (1980–2006)	Reported siltation: %	Quantity of silt removed: m ³	Terminal pumping station
				Vert.	Hor.					
Town	19.1	AJC Bose Road	4986	2.78	2.13	619	3433	50–70	12 069	Palmer Bridge
		APC Roy Road	4631	2.79	2.15	627	3769	70–85	12 288	
		Nimtola Ghat Street	1785	2.39	1.86	215	1678	70–75	4165	
		Beadon Street	747	2.42	1.89	114	787	70	1801	
		Canning Street	557	2.42	1.89	133	777	30	522	
		Kolutola Street	2000	2.42	1.89	258	1743	85	5749	
		Lenin Sarani	2787	2.39	1.88	333	1931	70–75	6668	
Suburban	25.7	Hazra Road (circular)	4044	Diameter 1.64–2.17		457	3249	75–80	8892 ^c	Ballygange
		Rashbehari Avenue (horseshoe)	4813	3.05	2.13	571	4242	70	362 ^c	
Total			26 350			3327	21 609		52 516	

^a Sewers are named after their alignment along these prominent roads. Sewers are oval-shaped unless indicated.

^b Maximum clear vertical and horizontal dimensions of sewers are indicated and it varies along sewer length.

^c Work is ongoing in these sewers.

Table 1. Major 'man-entry' brick sewers in Kolkata (Basu and Dey, 2012)

The £70 million renewal project for the most critical 26 km of brick sewers (priority phase 1) was approved in 2006–2007 for contributory funding under the Jawaharlal Nehru national urban renewal mission, a government initiative to develop and refurbish India's urban infrastructure. The cost was met by 35% federal funding through the mission, 35% funding from the government of West Bengal and 30% from KMC and other sources.

Global tenders were invited by the corporation in 2007 to award the works to contractors having adequate and proven track records to carry out a sewer rehabilitation programme of this magnitude and complexity. Work started on site in 2008 and is due for completion in 2014. The project was designed and is being supervised by KMC's planning and development department in conjunction with its sewer rehabilitation consultant.

3. Trenchless technology

A primary criterion for the project was to cause as little disruption to normal urban life as possible. Other issues considered were the extent of the programme, the sizes of the sewers involved, probable logistical challenges and suitable rehabilitation methods meeting the objectives. A decision to select a trenchless method was taken after careful review of available data and prevailing field conditions in the target area.

Trenchless technology was probably the only way by which a project of this magnitude could be undertaken and executed in such a heavily congested urban setting. Traditionally, brick sewer repairs were undertaken in open excavation for identification and accessibility. This involved shutting down roadways, diversion of traffic and stoppage or diversion of other utility services during repair. In such cases, the social costs could be many times the direct repair cost. The top half of the brick arch was usually dismantled, after which new brick walls were built on both sides and a reinforced concrete slab cast on top, with formwork removed by way of the manhole shafts. The original sewer profile was not restored.

Brick sewer rehabilitation has been done successfully using cast-in-place pipe lining in Newark (Pennington *et al.*, 2008). However, for Kolkata, inserting prefabricated glass-reinforced plastic (GRP) liners inside the existing sewers was judged to be the most suitable method. Major factors that dictated the selection were the suitability of application under prevailing field conditions, life expectancy of the product, track record, anticipated capital and operation and maintenance cost, available funds, product and skill availability, and size of sewer. Also, several other municipal corporations in India (Mumbai and Delhi in particular) have already resorted to using GRP liners for brick sewer repairs as an overall low-cost alternative to other methods of renewal (Downey, 2006).

The GRP liners selected for the project are type II 'stand-alone' liners as per the Water Research Centre manual (WRC, 2004). The liners are designed to withstand all overburden and hydraulic loadings with an expected life of over 50 years.

They are of the socket and spigot type, and are field-jointed with a rubber gasket after placement. The thickness of the liners was selected based on anticipated loading and they were tested in the laboratory for flotation, external pressure grouting, hydrostatic, and ground and traffic loadings.

The flexural modulus for short-term and long-term durability are 11 000 MPa and 5500 MPa, respectively. They are designed

to comply with deflection, strength and buckling requirements as stipulated by the relevant standards (ASTM, 2011; SA, 1989; WRC, 1986).

The smoother surface of the liners will offer less frictional resistance to flowing water and no reduction in the original hydraulic capacity of sewers is expected. However, the annular space between the liner and host sewer is a probable place for accumulation of gases (under anaerobic conditions) that could potentially have serious consequences during operation. The space is thus grouted with concrete of stipulated specification after installation of liners, which also improves its structural integrity (Figure 4).

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Figure 4. Typical cross-section of a glass-reinforced plastic liner inside an egg-shaped brick sewer – the space between the liner and sewer is grouted to avoid a dangerous build-up of gas (GRP, glass-reinforced plastic)

Due to tidal effects in the River Hooghly, to which most of the sewers were connected, submersible pumps of high discharge capacity and high delivery head were used to divert the flow

Figure 5. A horseshoe-shaped brick sewer ready for lining after careful de-silting

Figure 6. Liner sections being delivered at night, when most work was carried out due to reduced sewage flows

4. Logistical challenges

After work started in 2008, significant challenges were faced both by the contractors and KMC while working in what is one of the most congested urban areas in the world. Such challenges involved logistical, technical and administrative issues and had to be resolved quickly to maintain the project schedule.

In particular, there was very little reliable information about extensions to the main network that had been carried out over the last 100 years. A detailed closed-circuit television survey of the whole sewerage network was thus carried out after de-silting to record hydraulic properties, interconnections, status and the presence of other utilities, such as water mains, high-voltage electricity cables and communications cables. Before insertion of liner material inside the sewers could be started, all utility lines had to be isolated and then relocated in close coordination with the relevant departments.

Usually, flow diversion for major sewers is arranged by selecting an alternative sewer as a 'bypass'. However, in this case, no such sewers were available, so high-density polyethylene bypass pipes were temporarily laid along existing main roads parallel to the sewers. These were laid allowing passage for cross roads on either side of the main road.

Also, flow diversion is normally done by deploying self-priming pumps at the ground level, but in Kolkata the level of water in the sewers could not be controlled with such pumps due to tidal effects in the River Hooghly, to which most of the sewers were connected. As a result, submersible pumps of high discharge capacity and high delivery head were used to divert the flow. These pumps were found to be small enough to be accommodated inside the sewers and were sufficiently effective to drain the flow in a reasonable amount of time.

Flow diversion in the trunk sewers is generally done using pneumatic balloons for short periods and semi-permanent brick or stone walls for extended periods. However, balloons of sufficient size were not available locally, so shaped and stiffened steel plates were used as 'stanks' initially. Subsequently, much heavier reinforced-concrete-filled sections of GRP liner were used, measuring 0.3 m wide. It was possible to remove both types of stank quickly in the event of sudden and intense rainfall by using powered winches.

Removing silt from sewers posed quite a challenge as this was probably the first time such sewers were being de-silted since their commissioning more than a century ago. At many places, the silt was found to have formed rock-like deposits, which could not be removed by simple manual excavation (Figure 2). Chisels, jack hammers, ground breakers and even fork lifts at a few places were employed to dislodge solidified silt, although great care had to be taken not to damage the sewer structure (Figure 5).

De-silting produced a huge quantity of excavated material for disposal. The silt contained granular material along with clayey organic deposits, inert materials and traces of heavy metals. The estimated quantity of silt removed was over 50 000 m³, and it was disposed of in secured sanitary landfills in an environmentally acceptable manner.

Most of the rehabilitation work was undertaken during night hours (usually between 2300 and 0500), when wastewater flow inside the sewers was minimal (Figure 6). The only visible evidence of work on the surface was some barricading at certain places around access shafts and manholes, which caused some localised and limited restriction to traffic and pedestrian movement.

The liners had to be manoeuvred within very narrow streets in the city area and were lowered individually through access manholes for carrying them further inside the sewers for proper placement (Figure 7).

Connections to the major sewers are generally only at manhole locations, but several unauthorised connections were found between manholes. These were blocked with pneumatic plugs during lining work and then reopened.

5. Safety, sustainability and economics

Safety is a primary concern for sewer rehabilitation work, especially for people working within the sewers (Figure 8). The use of personal protective equipment was mandatory, including clothing, helmet, gloves, boots, belt, anchoring rope and face-mask, and a logbook was maintained for all workers entering the sewers. The complexity of the work and associated hazards were adequately explained to the workers by the supervising authorities.

All precautionary measures were adopted and strict adherence to these norms has resulted in no fatalities in 4 years. Carrying out most of the installation works during night hours significantly helped to avoid possible hazards associated with working during normal hours in such extremely congested urban areas. The working areas in congested roads and around access manholes were clearly demarcated, guarded and isolated during daytime for traffic diversion

and pedestrian movement.

With regard to sustainability, in addition to providing a significantly improved sewerage system with minimal social and environmental impact, the liners were manufactured locally – creating further employment and reducing material transport costs.

A cost–benefit analysis provides economic justification for the investment using a framework prescribed by the Asian Development Bank (ADB, 1997). Following data published by the Reserve Bank of India (Mohanty, 2011), the annual rate of inflation considered was 7.55%, and benefits from the project were deemed to accrue over a period of 39 years (2012–2050). Given that the renewal life of the rehabilitated components is estimated to be 70 years, the analysis covered approximately 55% of the life span of the project. This in turn resulted in a conservative approach, as extending this period would increase the benefit-to-cost ratio and make project more economically viable.

The most important benefits expected to accrue from the project are the health-related benefits and savings in income loss due to a reduction in flooding. Savings in health costs are mostly due to avoidance of expenditure incurred for waterborne diseases. Earlier studies (Roy *et al.*, 2008) had indicated monthly expenditure incurred by households in the city on treatment of waterborne diseases. The weighted average of the monthly expenditure is £5.35 per household at 2011 prices. Problems in accessing workplaces and carrying out usual business are some of the factors contributing to income loss. On the

Figure 7. Liner section being placed inside a sewer by way of an access manhole

Figure 8. All personnel working in the sewers were required to follow strict safety procedures

Brick sewer	Project schedule		Contract cost		Rehabilitation cost: £million/km	Contractor
	Start	Finish	INR million	£ million ^a		
AJC Bose Road	October 2008	November 2011	930	12.83	2.57	Angerlehner Hoch- und Tiefbau Gesellschaft mbH, Pucking, Austria
APC Roy Road	November 2007	September 2010	795	10.97	2.37	
Nimtola Ghat Street	November 2008	January 2011	383	5.28	2.96	Michel Bau GmbH & Co. KG, Neumünster, Germany
Beadon Street	November 2011	May 2012	158	2.19	2.93	
Canning Street	November 2011	May 2012	104	1.44	2.59	Angerlehner Hoch- und Tiefbau Gesellschaft mbH, Pucking, Austria
Kolutola Street	November 2007	January 2011	368	5.08	2.54	
Lenin Sarani	April 2008	May 2010	603	8.50	2.99	Michel Bau GmbH & Co. KG, Neumünster, Germany
Hazra Road	November 2011	May 2014	720	9.93	2.46	
Rashbehari Avenue	November 2011	September 2013	1018	14.05	2.92	Angerlehner Hoch- und Tiefbau Gesellschaft mbH, Pucking, Austria
Total			5079	70.27		

^a Adjusted for rate of inflation as indicated in the text and adopting midmarket rate in the middle of the calendar year 2011 for conversion of INR into £

Table 2. Project cost and current status (Basu and Dey, 2012)

Figure 9. View inside a smooth-lined, egg-shaped brick sewer – local residents and workers are immediately benefitting from improved sanitation and reduced flooding

other hand, cleaning of houses, establishments, cars and commuting in flooded areas are sources of additional expenditure. The average daily income of the households is assumed to be £6.63 at 2011 prices.

The cost-benefit analysis was carried out by using a discounted cash flow technique to obtain the economic internal rate of return and economic net present value for the investment. The economic internal rate of return was compared with the economic opportunity cost of capital. Given the complexity of estimating country-specific economic opportunity cost of capital, as followed in the case of the projects financed by the Asian Development Bank, an annual discount rate of 12% had been used as a proxy. This approach has gained recognition in the literature analysing the economic and social costs and calculating the benefits of infrastructure projects (Inocencio *et al.*, 2007; Murty *et al.*, 2006).

The calculated economic internal rate of return of the project was 15.35%, which is well above the 12% economic opportunity cost of capital, which is usually used as a criterion for assessment. The economic net present value was estimated as £18.35 million. Since economic net present value is greater than zero and economic internal rate of return is over 12%, the investment incurred is justified and economically viable as the economic benefits exceed the economic costs.

It is also important to note that certain benefits – reduced burden of vector-borne diseases such as malaria and dengue, improved environmental conditions, visual appeal of the city, reduction in traffic congestion, and reduction in emission of pollutants such as sulfur dioxide, nitrous oxides, carbon dioxide, particulate matters and black carbon – have not been considered in the cost-benefit analysis. Inclusion of such benefits and stretching the period of analysis covering the entire life of the project will further improve the economic internal rate of return and economic net present value.

6. Current status

The cost and current status of the various brick sewer rehabilitation works in Kolkata are given in Table 2.

Works for the sewers in the town system have been completed and the refurbished sewers have been re-commissioned (Figure 9). Works on two remaining main sewers in the suburban system are ongoing and scheduled for completion by 2014.

Significant benefits in terms of better sanitation and reduced flooding are already being experienced in the areas around the completed sewers.

The project team is now adequately experienced to continue with future rehabilitation programmes on Kolkata's brick sewers.

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