Repairs and Strengthening of Brick Arch Masonry Storm Water Drains for MCGM

ICRI 2019 Project Award Finalist – Project of the Year, Water Structure Category
Mumbai, Maharashtra, India

By Kasturi Projects PVT, LTD

Fig. 1: Completed repair of the storm water drains in the City of Mumbai, India, that are over a century old and were constructed of brick arch masonry during the British Era

The storm water drains in the city of Mumbai, India, are over 100 years old and constructed with brick arch masonry during the British Era (Fig. 1). The storm water drains (SWD) were prone to frequent cave-ins. To prevent cave-ins, enhance their safety, and maintain the SWD system, the Municipal Corporation of Greater Mumbai (MCGM), under the Central Government of India "BRIMSTOWAD" Scheme, initiated a detailed survey and mapping of the SWD for the City of Mumbai.

Many of the defects identified in the brick structures were related to breaks in the masonry lining, allowing the surrounding soil to be washed into the drain and creating voids in the soil. Voids behind brick arches and buried pipelines are detrimental to their structural performance as they benefit from an even distribution of load to remain stable.

CAUSES OF DETERIORATION

Some of the causes for the deterioration identified include:

- Brick arch failure due to surcharge loading. The overloading was due to additional structures constructed over these buried storm water drains;
- Imposed loadings from new roads constructed over buried structures, increasing the surcharge load;
- Surcharging when a drain is not watertight, allowing water leakage into the ground significantly increasing the potential for soil erosion in the ground surrounding the drain;
- Deterioration and spalling of lining and brickwork (Fig. 2), some due to scouring. There was also bond failure due to ingress of water, undermining the integrity of the lining through corrosive effluents;
- Erosion of mortar joints (Fig. 3) impaired the structural strength of the drain, which if not rectified, would result in misplaced bricks;
- Excessive loading was generally the cause of longitudinal cracking. Circumferential cracking was infrequent;
- At one location, roots of an appreciable size penetrated the brick arch construction (Fig. 4). In this case, local collapse of the brickwork was a real possibility in the short term; and
- Hydrogen sulfide attack on concrete and mortar was observed over significant lengths of storm culvert, which receives sewage and storm water. The sulfuric acid attacks mortar, including the mortar matrix of concrete. In places, this corrosive attack penetrated to a considerable depth in the soffits. Deterioration at the waterline was much less frequent but was still quite severe.

STRUCTURAL REHABILITATION

The structural rehabilitation addressed all aspects of upgrading the structural performance of existing SWD and drainage systems. Three approaches normally considered were:

Repair: Repair systems and methods are used to rectify damage to the structural lining or the reconstruction of short lengths of drain, but not those affecting the substantial lengths of the drain line. Repair techniques include the more conventional approaches generally practiced by the municipal body but with greater attention to detail and quality of repairs.

Renovation: The concept of renovation embraces potential cost savings by retaining the most existing structural system possible. Using renovation techniques in this project proved the most expedient and cost-effective way of maintaining "the existing hole in the ground" by stabilizing and sealing the sewer lining where it was deficient, and adding strength to whatever structural sections were still viable.

In Britain, renovation methods typically offer 50% - 80% savings over replacement costs as the linings of the drain can proceed without excavation, temporary support, back filling, and commissioning as accompanied by significant reduction in the disruption of flows, and indirect costs incurred by the community.

Replacement: Replacement is frequently the solution for substantial hydraulic under-capacity, complete structural inadequacy or where other measures, such as supplemental reinforcing, are impractical or uneconomic. In India—where some techniques are unavailable or involve expensive imported technology, and where labor costs are cheaper—replacement is, in almost all cases, less expensive than the current cost of renovation options.

SUMMARY OF REHABILITATION SYSTEMS

Many methods are currently available for the repair, renovation, and replacement of drains. As the rehabilitation of drains in this project was restricted to man-entry sizes generally larger than 48 in. (1200 mm), methods suitable primarily for smaller drains are not mentioned. Methods used on this project include:

- Structural stabilization by grouting and repointing the brick lined arch drains;
- Preformed linings using pipe insertions, preformed segmental linings, precast dry-mix shotcrete, slip lining, cured in-place soft lining, spiral lining, cement mortar lining, and sprayed epoxy lining; and
- In situ reinforced sprayed concrete linings with protective coatings that produce of a monolithic, smooth bore concrete lining reinforced with a specialized protective coating providing protection against extreme acid attack.

REPAIR SYSTEM SELECTION

After detailed analysis and various deliberations, the in situ reinforced sprayed concrete lining with protective coating, along with extensive two layer grouting of cementitious non-shrink grout and polyurethane resin grouts for water control was adopted by MCGM. This methodology was chosen considering the advantages of renovation over replacement.

Fig. 2: Delamination and spalling of brick lining

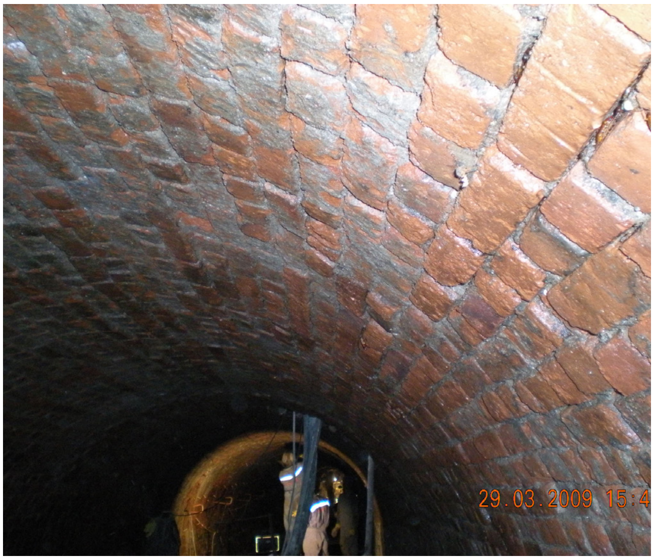

Fig. 3: Erosion of mortar joints

Fig. 4: Root penetration through masonry lining

SITE PREPARATION

The repair process began with diversion of traffic to access manholes that are primarily on the road. The 24 in. (600 mm) diameter manholes needed widening to facilitate entry for crew and equipment. Temporary coffer dams to stop the flow of water (even during summer) were installed every 650 ft (200 m) along the drain. These dams were necessary since the drains carried both storm water and sewage. To divert flow of water to the downstream side, submersible dewatering pumps placed on the upstream side of the coffer dams were augmented with separate 12 in. (300 mm) diameter temporary pipes running to the surface. The pumping operation continued 24/7 until the section of drain was completely repaired. We were working near a residential area so diesel-operated "silent" generators, air compressors, and receivers were used to keep the working noise levels within the permitted range during the continuous operations. Hydrogen sulfide and other gas levels in the SWD were monitored daily before human entry. An effective ventilation system, lighting system, and emergency evacuation lifelines along with oxygen cylinders were installed in the drain to give the workers a safe working environment.

SURFACE PREPARATION AND DEMOLITION

In most areas, the internal brick masonry lining was eroded. Where deterioration was evident, the old lining was manually removed with 11 lb (5 kg) breaking hammers (Fig. 5). Lightweight hammers were used to avoid disturbing the bricks and mortar lining. After removal of the lining, the debris generated was taken out of the drains manually. High-pressure (7250 psi [500 bars]) waterjet washing was used to clean the brick surface and remove loose, damaged mortar pointing (Fig. 6). Loose bricks, where removed, were replaced with new bricks.

REPAIR PROCESS

The repair process included the following:

- Longitudinal cracking at the crown was opened and sealed with a non-shrink polymer and fiber-reinforced mortar. Thereafter, a 4 in. (100 mm) wide by 4 in. deep x about 8 in. (200 mm) length opening was made in the crown of the brick arch masonry and four to six #5 (#16M) diameter T or FE 500 D grade (500 MPa [72,500 lb/in^2]) steel reinforcement pins were installed with mortar anchors and the opening filled with polymer modified fiber reinforced mortar to have an effective "crack stitching" of the masonry crown. This was repeated for the full length of the cracks at a 20 in. (500 mm) spacing;
- Repointing the mortar joints where eroded;
- Injecting a two component sealing rigid polyurethane resin to stop water ingress into the drains (Fig. 7);
- Installing reinforcement FE 500D per the structural drawings and anchoring to the brick arch masonry at sufficient interval with anchors and spacers (Fig. 8);
- Wet mix shotcrete, M-30 Grade (30 MPa [4300 lb/in^2), was applied to the entire brick masonry internal surface at a thickness ranging from 5 in. (125 mm) to 9 in. (230 mm) per structural requirements (Fig. 9). The application was completed in one or two passes per site conditions;

Fig. 5: Demolition of deteriorated brick lining with lightweight breaker

Fig. 6: High-pressure waterjet washing

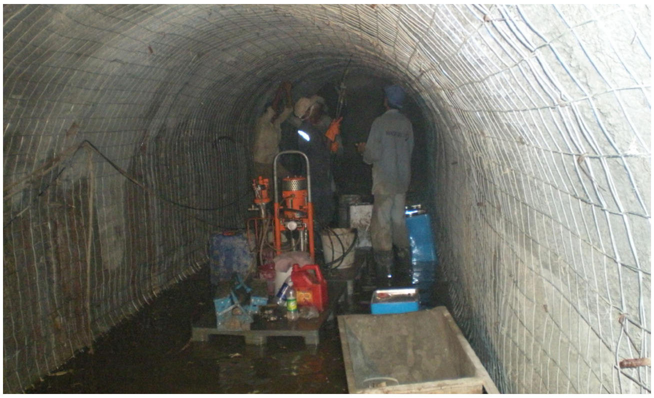

Fig. 7: Installed ports for injecting 2-component rigid polyurethane resin

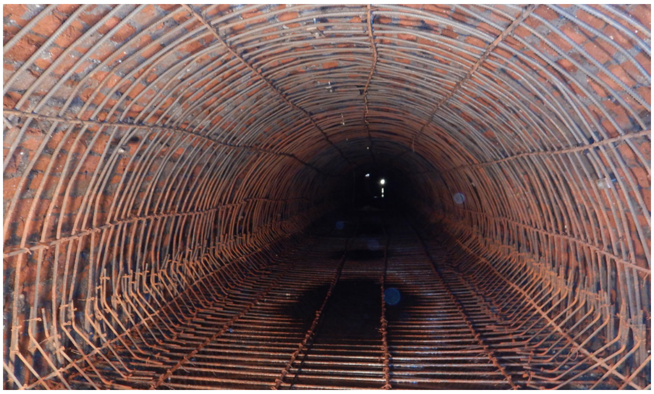

Fig. 8: Fixing steel reinforcement

- Drilling 1 in. (25 mm) diameter x 22 in. (550 mm) long holes into the brick masonry (Fig. 10), installing injection packers, and grouting using a non-shrink cementitious, anti-washout grout, to the point of rejection (Fig. 11). The goal was to fill the voids behind the buried drain structure and into the mortar joints to strengthen the pointing; and
- Spray applying a 0.25 in. (6 mm) thick two-component mineral-based mortar system to form a lining that is resistant to aggressive environments (Fig. 12). The ceramic-based mineral coating can withstand extreme pH (3-12), chloride and sulfate loading, biogenic sulfuric acid attack, and abrasion. In addition, the coating is breathable, preventing damage due to hydrolysis and osmosis.

SUMMARY

This rehabilitation model (upon successful testing) was adopted by the MCGM, and as of 2018, over 3.1 miles (5 km) of SWDs have been successfully repaired.

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Fig. 9: Placing wet-mix shotcrete

Fig. 10: Drilling holes into the brick masonry

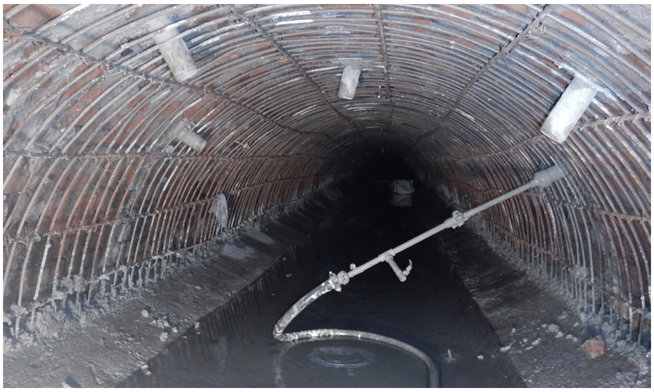

Fig. 11: Fixing injection packers and grouting using a non-shrink cementitious, anti-washout grout

Fig. 12: Spraying two-component mineral-based mortar system to form a lining

PROJECT TEAM

Repairs and Strengthening to Brick Arch Masonry Storm Water Drains for MCGM

SUBMITTED BY
Kasturi Projects PVT LTD
Thane, Maharashtra, India

OWNER
ME Infraprojects PVT LTD
Mumbai, Maharashtra, India

PROJECT ENGINEER/DESIGNER
S V Patel & Associates
Mumbai, Maharashtra, India

REPAIR CONTRACTOR
Kasturi Projects Pvt Ltd
Thane, Maharashtra, India

MATERIALS SUPPLIERS/ MANUFACTURERS
MC Buachemie (I) Pvt Ltd
Ponda, Goa, India

Totale Global Pct Ltd
Thane, Maharashtra, India

Rajendra Kasturi Pai
After graduating with a BA in Science, Pai went on to complete a MA in Management and then completed a certificate course in Public Health & Sanitation. Thereafter, he joined the late Mr. R. P. Kasturi in establishing a Private Limited Contracting Company in 1996, to carry out sand blasting and specialized coating works, and then graduated into concrete repairs, dry-mix shotcrete placement, and waterproofing. To further gain professional knowledge he attended several continuing education programs namely, Injection Repairs and Protection of Concrete Structures, a two-week course conducted by BZB; Krefeld Germany, BTS Tunnel Design; a Construction Course from the University of Warwick, UK; and a Grouting Fundamentals and Current Practices & Tunneling at Colorado School of Mines, USA. He also has attended several major manufacturer trainings in grouting from BASF, MC Bauchemie, TPH, and GCP De-Neef, to name a few. He has currently around 30 years' experience in concrete repairs, waterproofing, dry-mix shotcreting, plumbing, and sanitation. Plus, in the past 7 to 8 years he has started using wet-mix shotcrete as an extension to the dry-mix shotcrete experience.