FINALIST—2019 PROJECT OF THE YEAR

WATER STRUCTURE CATEGORY

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

MUMBAI, MAHARASHTRA, INDIA

SUBMITTED BY KASTURI PROJECTS PVT LTD

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

OVERVIEW

The storm water drains in the City of Mumbai, India, are over 100 years old and were constructed in brick arch masonry during the British Era (Fig. 1). The storm water drains (hereafter referred to as 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 fabric, introducing the possibility of the surrounding soil being washed into the drain and resulting in voids in the soil. Voids behind brick arches and buried pipelines are detrimental to their structural performance and benefit from an even distribution of load to remain stable.

CAUSES OF DETERIORATION

Some of the causes of deterioration identified included:

- 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 and water flows out of the drain into the ground that significantly increases 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 and 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 must be considered 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 foul sewage and storm water. The sulfuric acid attacks mortar, including the mortar matrix of concrete. In places, this form of corrosion attack penetrated to a considerable depth in the soffits. Attack at the waterline was observed much less frequently, but was severe.

STRUCTURAL REHABILITATION

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

Repair: Repair systems and methods are taken to mean the rectification of damage to the structural fabric or the reconstruction of short lengths of drain, but not measures affecting the whole or major part of the drain line. Repair techniques will form the more conventional approaches generally practiced already by the municipal body but with greater attention being paid to detail and quality of repairs.

Renovation: The concept of renovation embraces the potential for cost saving obtained by retaining as much as possible of the existing system. The application of renovation techniques in this project offered the most expedient and cost effective way of maintaining "the existing hole in the ground"; the means to stabilize and seal the structure where it is deficient; and the means to add strength to whatever is usefully available.

In Britain, renovation methods typically offer 50% -80% savings on replacement costs because savings are offered in the ability to restore the fabric of the drain without excavation, temporary support, back filling, and reinstatement as well as significant reduction in the disruption and indirect costs incurred by the community.

Replacement: Replacement is frequently the solution for gross hydraulic under-capacity, complete structural inadequacy or where other measures, such as reinforcement, 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, cheaper 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), those methods only suitable for smaller drains are not mentioned.

- Structural stabilization by grouting and repointing the brick lined arch drains;

Fig. 2: Delamination and spalling of brick lining

Fig. 3: Erosion of mortar joints

Fig. 4: Root penetration

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 reinforcement FE 500D

Fig. 9: Installing wet-mix shotcrete

- Preformed linings using pipe insertions, preformed segmental linings, precast gunite, slip lining, cured in-place soft lining, spiral lining, cement mortar lining, and sprayed epoxy lining; and
- In situ reinforced sprayed concrete linings and protective coatings that results in the production of a monolithic, smooth bore concrete lining reinforced with a specialized protective coating providing adequate protection against extreme pH attack.

REPAIR SYSTEM SELECTION

After detailed analysis and various deliberations, the in situ reinforced sprayed concrete lining with protective coating, along with extensive 2-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 rather than replacement.

SITE PREPARATION

The repair process began with diversion of traffic to access manholes, which are mostly on the road. The 24 in (600 mm) diameter manholes needed widening to facilitate entry for men and equipment. Creating temporary coffer dams to stop the flow of water (even during summer) at every 650 ft (200 m) length of the drain was necessary as these drains were not only carrying storm water but also sewage water. Fixing submersible dewatering pumps on the inward side were augmented with separate 12 in (300 mm) diameter temporary pipes along the surface, to divert flow of water to the downstream side. The pumping operation continued 24/7 until the section of drain was completely repaired. Diesel-operated “silent” generators, air compressors, and receivers were installed for continuous operation to keep the working noise decibels within the permitted range as it involved working near a residential area. H2S and other gas levels in the SWD were monitored daily before human entry. The drains were provided with an effective ventilation system, lighting system, and emergency evacuation life lines along with oxygen cylinders.

SURFACE PREPARATION AND DEMOLITION

At most places, the lining on the internal brick masonry was eroded. Where present, the old lining was removed manually with 11 lb (5 kg) breaking hammers (Fig. 5). Lightweight hammers were used so as not to disturb the bricks and mortar lining. After removal of the lining, the debris generated was conveyed out of the drains manually. High-pressure (7250 psi [500 bars]) waterjet washing was performed to clean the brick surface and remove loose, damaged mortar pointing (Fig. 6). Loose bricks, where removed, were re-constructed by replacement with new bricks.

REPAIR PROCESS

The repair process included the following:

- Longitudinal cracking at the crown was opened and sealed with non-shrink polymer and fiber reinforced mortar. Thereafter, a 4 in (100 mm) wide x 4 in (100 mm) deep x about 8 in (200 mm) length opening was made in the crown of the brick arch masonry and four to six No. 5 (16 mm) diameter T or FE 500 D grade steel reinforcement pins were fixed with mortar anchors and filled with polymer modified fiber reinforced mortar to have an effective “crack stitching” of the masonry crown. This was repeated for the length of the cracks at every 20 in (500 mm) length;
- Repointing the mortar joints wherever eroded;
- Injecting 2-component sealing rigid polyurethane resin to stop water ingress into the drains (Fig. 7);

- Fixing Reinforcement FE 500D per the structural drawings and anchoring the same to the brick arch masonry at sufficient interval with anchors and spacers (Fig. 8);
- Wet mix shotcrete, M-30 Grade, 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;
- Drilling 1 in (25 mm) diameter x 22 in (550 mm) long holes into the brick masonry (Fig. 10), fixing G.I packers, and grouting using a non-shrink cementitious, anti-washout grout, to the point of rejection (Fig. 11). The aim 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.


Fig. 10: Drilling holes into the brick masonry


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

SUMMARY

This rehabilitation model (upon successful testing) was adopted by the MCGM, and as of 2018, over 3.1 miles (5,000 Rm) of SWDs have been successfully repaired.

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

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