BOMBAY STORM DRAINAGE PROJECT

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INTRODUCTION

The basis of Bombay's Storm Water Drainage system was established in the 1850's and has developed subsequently as the city has expanded. No co-ordinated planning of the system has been carried out for some time and the rapid growth in population in the last few years has caused increasing problems of flooding and collapse. For these reasons the project was initiated.

The project period was for 2 years and included data collection, preparation of a Master Plan, Review of Operations and Preliminary Design.

Bombay is a city adequate for a population of about 5 million people but with twice that number and growing daily. It is subject to monsoon rainfall and much of the land is affected by tides. There are two distinct areas:

The City -the older part with more established development with a well developed underground drainage system; and

The Suburbs -substantially larger, not yet full developed but growing very rapidly, which has a mainly open storm drainage system and some large rivers.

At the start of the project the only record of the drainage system comprised a few lines on plans with no manhole locations or level information. Before work could start a network of 200 benchmarks was established for level control. Some 18,000 manholes were surveyed in the City and, for entry into an STC25 database, a grid system was established on the topographical survey plans. The condition survey requirement was for all man-entry sized storm water sewers, approximately 80 Km, about 20 Km of man-entry foul sewers and 20 Km CCTV survey of smaller sewers. No previous experience in the techniques were available in Bombay and all equipment for CCTV had to be imported.

In the suburbs all open drains 1.5 m or wider were to be surveyed with cross sections prepared at 10 m intervals. A total length of about 300 Km was surveyed.

No return storm frequency analysis was available. Records dating back 100 years from the two permanent rain gauges were therefore analysed and frequency / intensity / duration relationships established. From this information families of hyetographs were developed.

THE CITY AREA

The City area originally comprised seven separate islands. The gaps between the islands were sealed and the enclosed area reclaimed for development. This has resulted in many areas close to high tide level and drainage runs around the original islands to avoid expensive excavation in basalt. Although no point in the city is more than 1 Km from the coast, drainage runs are up to 5 Km in length. The monsoon pattern of rainfall results in eight months with small quantities of foul flows in the system, which has to discharge very large quantities a few times a year.

The central business district of Bombay is located on the southern extremity of the city with the main work force living in the suburbs to the north. The main commuter routes are two railways and two roads running from north to south with about 1.5 million railway movements per day. The railway is, in many places lower than the surrounding ground and therefore is the first to flood. Flooding invariably disrupts train movements and any serious flooding paralyses the city. Bombay is the most important commercial centre in India, a leading industrial centre and handles most of the country's imports and exports. For each day of disruption losses were conservatively estimated at Ru. 350 million, approximately £8 million. Systematic records of flooding had not been kept, except in recent years, but the evidence available suggests that incidence has increase from 2 days per anum in 1951 to 6 per anum now.

The monsoon conditions result in very high intensities, even for frequent return periods and in such conditions some disruption to movement is expected during heavy rainfall. Costs of improvements to design against flooding of roads and railways for infrequent storms are prohibitive, even with the high cost of disruption. The consequent maintenance problems due to low velocities in normal monsoon conditions would also be unacceptable. Designs were therefore based on avoidance of disruptive flooding for a twice in one year event. Solutions were tested against more extreme events to ensure a rapid reduction in water levels at the end of storms which was possible due to the nature of the catchments.

Verification against flow surveys was problematic due to the high volumes of silt present in the system, the tidal influence which extends over 1 Km up the major systems and the high cost of importing the equipment and organising the flow survey in India. Models were verified against known flooding locations.

A total of 47 separate catchment areas were identified in the City. Three areas cover more than 50% of the land and were those with most hydraulic problems. Many of the others were small coastal systems. WALLRUS models were built of each system. A methodology was established whilst working on the smaller areas and careful programming was required to ensure that data collection, modelling and development of solutions could proceed in each area in turn to achieve the tight time schedule.

A wide variety of construction methods was found particularly in the larger drains including some fine examples of brick and masonry arches, similar to those found in many cities in UK. The condition of many of these arch structures was good, particularly where no modifications had been made since they were built.

The major problems identified are summarised below.

Obstructions

Over 650 obstructions were identified in the 80 Km of storm drain surveyed. Most of these were water and other service pipes built across the drains resulting in restrictions of up to 80% of the cross sectional area. It was common for the drains to be inadequately repaired where they had been broken to receive these pipes and many of the structural problems were related to these sites.

Foul Flows

Although there is a separate sewer system, about half of foul flows enter the storm sewers. There are many expedient connections, inter connections between the two systems and overland flow from blocked or inadequate foul sewers. During the long dry season of about eight months, this represents the total flow in the storm system and causes deposition of silt and debris, corrosive atmospheres and very serious pollution of coastal waters and the major open channels.

Siltation

Siltation is a very serious problem, partly caused by the foul flows in the dry season. Available head to discharge by gravity is very small, gradients are therefore very low and velocities sluggish for most of the monsoon season when rainfall is light and during daily tidal flows. Most desilting is carried out by manual methods prior to each monsoon but is largely ineffective. Very considerable efforts were made to clean sewers to enable the survey to proceed but substantial volumes were still evident.

Structural Degradation

Where brick and masonry arches remain as constructed they showed remarkably little deterioration for most of the length. There were some lengths of severe fracturing and missing or hanging brickwork. Mortar was missing in many places and a repointing programme was proposed to prevent further deterioration which would require substantial renovation schemes.

Lack of Capacity

Traditionally storm sewers have been designed to take 25 mm/hr from the connected areas, regardless of time of concentration. This compares with 50 mm over one hour for the two in one year design event. This coupled with the high level of development which has taken place in recent years, increasing the impermeable areas has resulted in much of the system being considerably under capacity.

LEVELS OF SERVICE

The following four Levels of Service were evaluated:

Level 1	Prevent further obstructions which would stabilise the disruption at 6.5 days per anum instead of a continuing increase.
Level 2	Maximise existing capacity by removal of obstructions and an effective desilting programme, which would reduce disruption to 4.5 days per annum.
Level 3	Provide capacity to prevent disruption in a twice in one year storm coincident with high tide which it was assumed would reduce disruption to one day per annum.
Level 4	Provide capacity to prevent disruption during a one in once year storm coincident with high tide which it was assumed would reduce disruption to one day every two years. The additional cost of this level exceeded the benefit obtained.

Solutions proposed included reducing lengths of sewer run by construction of new interceptors to the coast, major pumping stations to lift flows above the tide level and increase of capacity of sewers. Storage schemes were considered but scope was limited due to the very high volumes involved and the shortage and high cost of land. The storage schemes which were feasible were more expensive than pumped options.

THE SUBURBS

The drainage system in the suburbs comprises mainly of open drains or 'nullahs'. The project only required survey and consideration of those nullahs in excess of 1.5 m width which excluded a lot of the system. Methods were developed to represent attenuation from the contributing areas for the purposes of WALLRUS modelling.

There were 74 separate catchments in the suburbs some of which were very large.

The major problems were lack of capacity and severe restriction in width due to developers 'stealing' the nullahs to create land for development. In places nullah widths had been reduced by over 70% by developments.

As in the City, siltation and obstruction by services was also a serious problem.

A number of housing schemes had been built in natural flood plains and it proved uneconomic to reduce flood levels in some of these locations. Isolation of local systems and pumping during times of heavy rain was the proposed solution.

Solutions generally involved widening and where necessary re-routing nullahs to provide sufficient capacity.