Virginia sewer experiment data used in

NINETEEN YEARS AGO a 65 m experimental sewer section was commissioned in Virginia, Free State. It comprised three sets of 900 mm diameter concrete pipe, each of which contained nine different types of cementitious materials. In the intervening period valuable information was obtained by monitoring the performance of these materials, and this information has now been combined with the predictive theory, developed in the United States and known as the Life Factor Model (LFM), to produce a sewer design manual. It will be published later this year by the PIPES Division of the Concrete Manufacturers' Association (CMA).

The Virginia sewer operates under very aggressive conditions and is the only such experiment ever to have been undertaken anywhere under such conditions. At the outset, predictive theory indicated that a standard concrete would corrode at a rate of ±6,5 mm per annum whereas a dolomitic aggregate concrete – the traditional solution for sewer pipes – would corrode at a rate of ±1,3 mm per annum. This meant that the traditional solution, which had proved effective on most sewers, would not be suitable for a sewer with a life expectancy of at least 40 to 50 years under such aggressive conditions. Therefore, the project specification called for either a lined concrete or a coated fiber cement pipe. A by-pass section was also constructed so that effluent could be diverted around the experimental section during inspections.

ROUTINE INSPECTIONS

The first decade

Regular inspections took place during which material losses were measured and gas readings taken. Initially sections of the pipes were also subjected to pure acid tests in the Boutek laboratory at the CSIR in an endeavour to obtain correlation between a laboratory test and site conditions.

After two years some clear trends could be identified:

- The difference between the performance of concretes made with dolomitic (DOL) and siliceous (SIL) aggregate could be clearly seen. On the former both the binder and aggregate were corroded whereas on the latter it was the binder only
- Concrete made with calcium aluminate cement (CAC) appeared to be performing more effectively than concrete made using Portland Cement (PC)
- Although the asbestos fibre reinforced (AC) pipes had corroded, the corroded material did not break off. Instead it remained intact but swollen, owing to fibers in the pipe wall which held the corroded material together
- All the protected pipes performed satisfactorily, except where the coatings were damaged
- The pure, or mineral acid attack in the laboratory, showed little correlation with the biogenic attack in the experimental sewer

The five-year inspection confirmed the two year findings, but the differences between the performance of the materials was now more marked. The most significant findings on the unprotected pipes were as follows:

- The PC/SIL concrete was performing as predicted
- The PC/DOL concrete was performing better than the PC/SIL concrete but not quite as well as had been predicted. This was due to varying rates of corrosion between the aggregate on the one hand and the binder on the other. Some aggregate fallout was also observed
- The CAC pipes were performing better than the other unprotected pipes and certainly much better than predicted
- The unprotected AC pipes were performing close to what had been predicted providing the depth of the soft corroded products was deducted from the wall thickness

These findings led a pipe supplier and a CAC supplier to investigate the feasibility of making pipes with a CAC/DOL concrete. This proved too costly, so a method of incorporating a CAC/DOL corrosion control layer on a host pipe made of PC/SIL concrete was developed. This approach has subsequently been applied to many South African sewers since 1997 and their anticipated life is several times greater than those sewers manufactured with the traditional dolomitic aggregate concrete.

sewer design

1 A series of 250 mm long pipe samples which were placed in a manhole during 2005
2 A CAC/SIL sample pipe with ± 30 mm lost due to corrosion. It was located next to a coated FC pipe with a wall that had swollen from its original thickness of 30 mm to 150 mm
3 This CAC/SIL pipe was installed in the sewer in 1989. Roughly 30 mm of this pipe was lost to corrosion while a PC/SIL pipe lost 84 mm during the same period (12 years)
4 New samples which were placed in the sewer during 2005 showing signs that corrosion has begun

Based on information available at that time it was assumed that CAC/DOL concrete would corrode ten times slower than PC/SIL concrete. Samples of CAC/DOL plus other materials were placed in the sewer and their masses were checked regularly as a means of predicting their corrosion rates. It should be noted, however, that mass loss is only an indication of corrosion rate and should be used in conjunction with the relative corrosion rates of aggregates and binders. The comparative rates of mass loss tend to be somewhat lower than actual corrosion rates.

As the application of the CAC/DOL layer was a wet-on-wet process and this corrosion control layer was compacted into the host pipe, there was an affective bond and an aggregate interlock between the two layers. For many sewers with moderate to severe corrosion the use of this concept of the CAC/DOL corrosion control layer made for a more cost-effective solution than either the inert cast in lining or the traditional dolomitic lining. Providing conditions are not excessively aggressive, this solution is applicable to pipe diameters of 300 mm to 1 200 mm.

The second decade

After 12 years the deterioration of the three siliceous aggregate pipes was so severe that they were on the point of collapse. To prevent this from happening sewage was diverted through the bypass section until the necessary remedial work had been done. As had been anticipated, the 84 mm walls had disappeared completely in some sections, indicating a corrosion rate in excess of 7 mm per annum.

The three badly deteriorated pipes plus sections of pipes on either side of them were removed and replaced with manholes. Detailed measurements were then taken to ascertain the relative corrosion rates of the different materials. The measured relative corrosion rates for the unprotected materials, using a value of 1,0 for a PC/SIL concrete, were:

- 0,4 for PC/DOL
- 0,25 for CAC/SIL
- 0,32 for FC
- An estimated 0,09 for CAC/DOL

These values can now be used in the predictive equations of the LFM, developed in the US and based on a PC concrete, by adding a material factor equivalent to the relative corrosion rates given in the preceding paragraph. Given that the host pipe can meet the structural requirements of a sewer and the corrosion

5 Kassie Botha, who is looking after the project on behalf of PIPES cc, removes the lid of a sample pipe before weighing and checking it for corrosion

6 The fourth manhole before the top slab was placed into position

control layer its durability requirements, and providing that operating conditions and effluent composition have been established, appropriate pipe choices can now be made to provide the most cost-effective sewer piping solutions for the requirements of a particular sewer. The CMA's sewer design manual will describe how this is achieved.

THE FUTURE

Extending the use of the experimental facilities

The information obtained to date is limited to a few of the possible materials that could have been used as corrosion control measures and there is still considerable scope for further refinement. With this in mind, new 250 mm long pipe samples have been placed in the manholes that were constructed in the gaps left by the pipes that were removed. Placing these pipe samples in manholes introduces a significant change to the way in which inspections are done as it is no longer necessary to divert the flow through the bypass section. The pipe samples have removable top sections which can be measured and weighed. Such an exercise was done earlier this year and indications are that the corrosion loss will be measurable later this year, three years after the pipes were installed.

The additional samples placed in the new manholes all consist of unprotected concrete in three categories, namely:

- Concrete made using PC cement with extenders
- CAC linings integrally cast into the host pipes
- Mortar-lined pipes using both PC and CAC

These additional samples are intended to yield more accurate information than was the case during the first decade of measurements. In particular, the performance of the CAC linings with different aggregates and different proportions will be assessed, as will the influence of various extenders on the performance of PC.

International applicability of developments

Although there has been considerable research on sewer corrosion internationally, South Africa is the only country where a section of live sewer has been set aside to test the performance of materials under very aggressive conditions. International CAC suppliers have shown considerable interest in the new manholes and they have co-sponsored the construction of a fourth manhole completed at the end of 2007. When used in the LFM, the data gleaned from this project will also be applicable to other countries, in particular those with developing economies. Many of these are located in warmer climates where sewer conditions are similar to or even more severe than those experienced in South Africa.

ADDITIONAL CONSIDERATIONS

Until quite recently sewers were designed for a 40-year lifespan (one generation). This shortsighted approach, especially when applied to sewers and other buried pipelines, is highlighted every time a sewer fails.

Current thinking maintains that a sewer should be designed for a much longer service life, at the end of which rehabilitation rather than replacement should be the preferred route. This means that outfall sewers should not simply be installed and forgotten about. After a certain age they need to be inspected and then assessed on a regular basis so that economical rehabilitation can take place and costly emergency replacements avoided.

The development of the LFM some 30 years ago provided a tool which is used to predict corrosion potential in a sewer operating under a given set of conditions. The development of better materials, based on the performance of the samples in the Virginia experimental sewer, means that concrete pipes which can handle the conditions in almost any sewer, are now available. Depending on these conditions, in very broad terms this means that in South Africa:

- Traditional PC/DOL pipes with a sacrificial layer are applicable to 60 % to 70 % of sewers up to 1 200 mm in diameter
- Pipes with a CAC/DOL corrosion control layer are applicable to about 30 % of the sewers up to 1 200 mm in diameter
- Pipes with cast-in HDPE linings are applicable to a very small percentage of pipes less than 900 mm in diameter where conditions are very aggressive and will compete with the other solutions on a project by project basis with pipes from 900 mm to 1 200 mm in diameter
- For pipes larger than 1 200 mm in diameter most sewers should probably be specified with a cast-in HDPE lining. There are two advantages in using an HDPE lining on these pipe sizes. The smoother bore offers greater hydraulic efficiency, hence a smaller diameter can be used, and the cost of the lining relative to that of the host pipe decreases as the diameter increases

The South African concrete pipe industry now supplies a full range of sewer pipes, offering sewer owners and designers the most cost-effective solution to meet the design life requirements for any sewer, no matter how aggressive the conditions. They will be further assisted in making the right pipe choices when CMA's sewer design manual is published.

Alaster Goyns
Piping Consultant

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