SEWER LININGS - THE FAILURES, COMMON REASONS AND NEW INNOVATIVE LINING TO INCREASE RELIABILITY OF RESTORATION

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Concrete structures are an integral part of society. Today most sewerage systems are constructed from concrete as the foundation. Concrete is susceptible to corrosion under many conditions and in sewers the acidic waste can degrade the concrete asset quickly without protection, and lead to a failure of this foundation system.
The Sewer Mains are predominant concerns however an often overlooked concern is with Man Holes, Wet Wells, Access and Inspection Chambers where the moist environment and stagnant air flow allows corrosion to readily occur.
Considerable effort goes into the design and construction of concrete structures, the concrete pipes, sewerage pumping stations and sewerage treatment plants. These represent considerable financial investment and with clear appreciation of options to protect these assets and how they perform in the future will provide maximum operational life.
There are various ways to protect concrete from corrosion in sewerage related installations. This is a simple overview of the common systems in use and outlines the various products strengths and weaknesses, and introduces a new novel approach based on traditional proven practices.

KEYWORDS
Man Holes, Wet Wells, Access and Inspection Chambers, Hydrogen Sulphide, Sewer, Corrosion, Concrete, Waste Water Treatment Plants (WWTP), Rehabilitation.

1 INTRODUCTION

Sewer mains, man holes, wet wells and other associated assets are all referred here to as underground asset. Concrete has been the predominant material of choice. It is relatively inexpensive, easy to cast or shape allowing it to be precast or laid in-situ, and can be connected using a variety of techniques.
As a construction material, it is ideal but in underground assets, concrete can be degraded by corrosion by waste and effluent which often consists of a variety of chemicals including sewerage. To protect the concrete from deterioration, admixtures, linings, coatings, and other fixes are applied as a membrane or barrier.
This paper discusses primarily issues of existing assets and rehabilitation, the general conditions and fixes applied, the reasons for limited success and risks to long term service, and will conclude with an innovative means of increasing reliability in providing the protection.

2 DEGRADATION OF CONCRETE

Specifically the area of focus here is corrosion from internal flows, and does not include the corrosion that can arise from surrounding sulphate soils, or internally from AAR (Alkali Aggregate Reaction).
Corrosion resulting from internal flows can be expected to arise from chlorides and nitrates in trade or industrial waste, however sulphur is also arising from this waste. The most common or predominant cause encountered is sulphur from various organic and materials carried in our sewerage and is derived from the sulphates present, interacting with microbial materials. The havoc is often loosely referred as Sulphurous Acid but many different events and compounds can be present.

$S_2^{=} + 2H^{+}$? H_2S because under anaerobic (bacteria slime) conditions $SO_4^{=}$ can form $S^{=}$

The H_2S gas rises to the vacant space and in the presence of oxidizing bacteria, have the H_2S react with airborne O_2 to form H_2SO_4

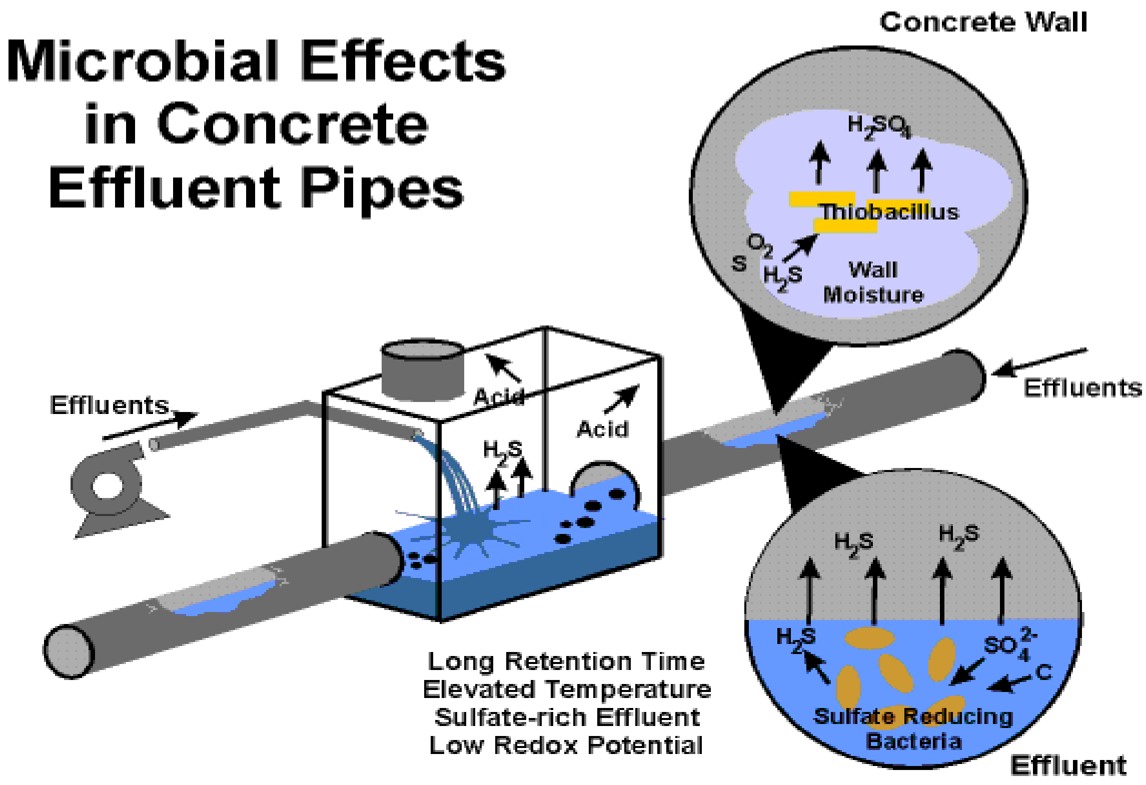
$H_2S + 2O_2$? $2\ H_2SO_4$

H_2SO_4 can then react with the Calcium Hydroxide (Hydrated lime) resulting in Calcium Sulphate, being the loss of concrete structure.

$H_2SO_4 + Ca(OH)_2$? $CaSO_4 + 2H_20$

H_2SO_4 is not in solution, but produced on the open damp areas of concrete and amount of acid produced (bacteria dependant) is in low concentrations and localized. The reactions take time; it is not a significantly large scale effect.

The following simplified diagram represents the activity in a pipe but is equally relevant in other assets.



3 PROCTECTING CONCRETE FROM DEGRADATION BY CORROSION

Although various options existing in protecting concrete from corrosion, those relating to dosing the flows depend on consistent monitoring and accurate dosing to the corrosive compounds present. It is impractical unless batch treatment is possible and given the potential volume of sewerage involved an expensive effort. Even treating the sewerage at a designated WWTP relies on coatings and linings when enclosed facilities or odour control is practiced. The concrete is best protected by a barrier.

There are many materials capable of doing this, thermoset and thermoplastic materials, rubbers, cement compounds, and a whole host of hybrid materials. Steels and their alloys are rarely used due to the inability to cover the range of chemicals potentially in the exposure stream, installation is difficult, and those that are suitable are very expensive.

Typically, the materials more commonly used are the following:
1/ Epoxy – 2 pack coatings and linings
2/ PVC – Polyvinyl Chloride preformed plastic
3/ PE & HDPE – Polyethylene and High Density Polyethylene
4/ Cements, Polymer Cements or Aluminates – Lime and related reactive cement bases

It is accepted there are many more varieties used in different parts of the world, and many hybrids of those mentioned but the greatest proportion are the 4 types mentioned here. It would be difficult to do justice to them all, or this subject in the allotted time so I will not be referring to those.

4 FAILURES OF THE COMMON MATERIALS

I refer to failures as the significant aspect of this paper because although each material has been found to be acceptable in providing protection in service, in sewerage rehabilitation it is the practical installation and ability for that material to sustain integrity over a broad range of conditions that limit life. Conditions that can cause premature failure is essentially the weak link and from which consideration made.

1/ Epoxy

These are by far probably the most common materials in modern use of the non-sacrificial types that demonstrate both versatility and resistance to the exposures.. Dating back to simple 2 pack paints, the difficulty in covering severely degraded surfaces resulted in failures from pinholes and loose substrate. These failures led to smoothing the substrate with sacrificial materials like cement render that altered the mode of failure to coating delamination from the render due to either contamination of the cement from the environment vapour during cure, the render itself letting go of the primary concrete due to poor adhesion, or the retained water in the render blowing off the lining. Epoxy based mortars are often incorporated to provide a smooth finish but the time to overcoating allows contamination of the surface and possible peeling. Subsequently, higher build epoxy were introduced which still had difficulty providing a proper barrier over extremely damaged concrete. Further developments led to fast cure epoxy types that allowed heavy builds over semi cured epoxy allowing the possibility of very high build but these systems are invariably exothermic in nature and the heat would draw moisture from within the concrete to the surface compromising adhesion. Alternatively the system itself on cooling would be contracting resulting in significant tension and the risk of failure referred to as mud cracking, or simply peel away from the existing substrate.

2/ PVC

In many ways, these materials appeared ideal. Shaped or preformed and able to be welded, they could be slipped into place and back filled if necessary to bed into the surrounding asset. Over time, degradation of PVC through plasticizer migration leads to a more brittle material and the lack of adhesion to the substrate leads to fractures that hide corrosive Hydrogen Sulphide ingress and degradation of base substrate, and thus inspection is never properly carried out. The longer term damaged can be extreme with collateral damaged to the asset or adjacent structures. The other issue with PVC is the inability to terminate properly the liner so the incidence of Hydrogen Sulphide vapour in behind the liner occurs often as condensation of the more corrosive acid resulting in a similar risk of asset damage and collateral damage.
There are other suggestions of PVC breaking down over time liberating Hydrochloric Acid and therefore itself being responsible for degradation of the asset, similar to that seen on steel roofing. This is a technical discussion with many varied opinions because those failures are centred on moist conditions and sunlight or heat. There is very little documented technical prof pertaining to this type of failure but it remains for the purposes of this paper technically feasible.

3/ PE & HDPE

Polyethylene followed on from the PVC as a material that overcame greatly the longer term degradation and embrittlement issues of PVC. Over a brief period of time some failures caused by the PE creeping with thermal changes in the environment resulted in fractures of the welds, or large areas letting loose till fatigue led to ingress or Hydrogen Sulphide or sewerage inflow. These failures were quickly identified and the introduction of High Density Polyethylene quickly introduced. Many of these liners included tags or mushroom shaped clips that were formed or welded to the back of the HDPE and encapsulated by the back fill of mortar after installation, providing greater support across large areas. Instances of weld failure were still a potential risk, and ingress at the termination however, the advent of fabric backed HDPE which was welded to the existing liner allowed the fabric backed section of the liner to be terminated using epoxy adhesives and fibreglass.

There are now many types and variations of this type of liner being installed. In terms of resistance to the corrosive conditions in sewerage environments, they are marvellous. History is yet to decide the longer term suitability of the HDPE liners with many maintenance teams expressing the same misgivings as for any preformed liner, how do you check over time the ingress of inflow behind the liner and be able to address any seepage before substrate degradation and collateral damage on adjacent structures occurs. In simple terms, what you cannot measure you cannot manage.

4/ Cements, Polymer Cements or Aluminates

Although these materials do not possess the chemical resistance to provide long term protection, they are finding renewed favour in rehabilitation work for the reasons of low cost. It is almost like the trends of change have come full circle. Modern materials are giving way to the traditional cements and hybrids referred to as Polymer and Aluminates. The primary motivation is to rehabilitate the assets prior to loss of structural integrity and allow the lining to be sacrificial. This is not uncommon, we see the technical treatise of steel pipework in refineries where the corrosion rate of the pipes are measured and time to replacement planned. In a modern refinery these practices are as much a process requirement as it is a safety issue. The economics and operational parameters make it viable given the type of degradation experienced in a refinery whereas in the utilities domain, maintenance of live assets around a bustling community has limitations and a distinct demarcation exists between those that believe the new HDPE type liners can provide 50 years life and those that appreciate that nothing can go on without some monitoring and the costs associated with cement type rehabilitation allows monitoring and expense to be levelled as needed, where it is needed, containing the risk to the primary asset.

It is clear that each rehabilitation liner has its own advantages and disadvantages. The period of installation history for many is short in years so monitoring and reporting on the success of each is in the hands of personal choice and the technical debates influenced by marketing and financial concerns.
It is therefore realistic to postulate that 2 schools of thought exist. The first is to look at the materials that theoretically on paper provide 50 year life without consideration for the management of potential failures and collateral impact on adjacent structures. Will those that select these be around to concern themselves with any negative impact? The second is to revert to traditional liners whether they be fully resistant to the corrosion or be they sacrificial in nature, but importantly be monitored for maintenance but can necessitate an ongoing allowance for rehabilitation that will impact the community in relation to inconvenience and ongoing use of taxes and resources.

5 INNOVATIVE NEW MATERIALS

The earlier reference to the trends of change having come full circle are not necessarily correct, and I expect trends will continue to be re-introduced time and time again. Cyclic yes, but at each cycle something more comes from the older material being reintroduced.
The times when epoxy was seen as the ideal material may be back among us with more value and advantage than ever before. Long life and the ability to monitor the integrity of any asset is a basic necessity, just like a medical check-up. The advent of renewed developments focused on better configuration provides the springboard to using technology that was fundamentally sound, and adapt fundamental installation practices to install linings with reduced risk of failure. Certainly more optimistic than new materials unproven in the field

Personally, we are one of the organisations taking traditionally sound materials demonstrated that perform historically, and focused on how to place them easily and quickly.

The main challenges have essentially been:
1/ Application to sound concrete substrate
2/ Application fast enough to eliminate the effects of contaminants to the liner system
3/ Application thick enough to provide adequate coverage that ensures a barrier free of imperfections
4/ A material that has low exotherm so no tension or stresses are present
5/ A material that can be quickly patched if ever required without total removal and replacement

Addressing each of these points more specifically.

1/ The modern techniques of concrete preparation allow significant improvements in speed and thoroughness of preparation. The research work on concrete and being able to incorporate this into the procedure provides significant benefits. Expansive gypsum or ettringite can be overcome to arrest coating blowing off, and aggressive media can be added to high pressure water preparing the substrate to quickly remove sulphurous build-up to leave the concrete clean. Fans and dehumidification equipment can be employed to rapid dry surfaces.

2/ Cement type liners can be placed in a very short space of time using modern equipment, so too can the coatings so intercoat exposure to the environment can be eliminated. Importantly the use of more conventional spray deposition equipment becomes more viable rather than heated lines and plural spray since the added complexity serves only to increase costs and reduce the number of people that can carry out the task without equipment failure or availability. Installing preformed plastic liners can be time consuming but the continuity of the liner as it is installed limits environmental influences and so they are suitable as materials under these criteria.

3/ To date the materials that have been able to be applied at thickness to provide the coverage or integrity in laminate required to eliminate risk in continuity in the lining have been the PVC, PE, HDPE, Epoxy mortars or those loosely based on Cement type mortars. Epoxy required overcoating and it is the delay between coats that introduced adhesion problems and peeling. More recent Epoxy types can quite easily be applied at high thickness overcoming the shortcoming of Cements appreciating that the cements are sacrificial to the corrosion.

4/ The latest and newest Epoxy based termed Ultra uses the same background systems as in the past, the proven performance experienced over the past 40 years has not altered so the recorded history over this same 40 years is well placed to provide the performance expectations in predicting asset reliability and life. The use of plural heated systems is not required alleviating exotherm, a critical factor in high thickness application because any system that cures hot must cool and therefore the post cure dimensional cross section will be under contraction load or tension - without balance.

5/ Inevitably, any lining must undergo some form of damage whether it be a retrofitted ladder, screen, or fatigue. The Cement type liners and epoxy based have demonstrated that simple patching or repair can be carried out without a great deal of effort and without skills and equipment that make such an exercise beyond the scope of the average handyman. Welding of plastics in repair is possible but the skills of the workforce require training and the level of preparation is not always simple to get good adhesion or reduce weld embrittlement.

	Ease of Application	Effects of Corrosive Conditions	High Thickness	Low Internal Stress	Ability to Patch
Traditional Epoxy	X	X		X	X
PVC		X	X	X	
PE & HDPE		X	X	X	
Cement based Mortars	X		X	X	X
Modern Epoxy Type (Ultra)	X	X	X	X	X

Reviewing the table, only the newest Ultra material demonstrates the versatility across the important criteria listed. It is a subjective review but each point has been considered by reference to industry (reference section 7, Acknowledgements). The Cement based Mortars deserves special mention because of ease of inspection and maintenance but the new type of Epoxy Ultra appears to have a significant advantage. If the long term resistance to sewerage environment is considered, the new Epoxy Ultra is certainly a material that deserves greater consideration.

6 CONCLUSIONS

There are many materials as either hybrid types of the aforementioned, or consisting of entirely different technology that have been used in the rehabilitation of sewers. These have, from time to time included polyurethanes and polyureas, fibreglass laminates and methacrylates. Unfortunately they have not taken to the industry well and suffer from either confined space issues pertaining to flammable solvents or require primers or are water sensitive. Failures and difficulty with installation make them unsuitable for use across a broad range of practical considerations. We still see today the majority of discussion and proposals based around the same few materials that have been in use for decades, and will continue to be used for decades to come.

The newer preformed plastics will continue to be offered to the market and appear to have a place during new construction however ongoing issues pertaining to termination of the plastic and how to ensure any seepage behind the liner is still a concern in being able to identify this before major damage occurs.

The new Ultra technology has none of the shortcomings of earlier systems and has the demonstrated chemical resistance to be a firm advantage, not relying on the promise of 50 years maintenance free life – yet quite possibly achievable, providing the integrity of the asset itself is not compromised. Given the fact it lends itself to be able to be repaired in the field with relative ease leaves it a very practical consideration.

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