Road Concrete Manhole Damage By Wastewater Disposal Systems

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Abstract

Wastewater disposal systems consist of concrete pipes, cast iron pipes, PVC pipes, manholes, pump stations and interceptors. Sanitary sewer pipeline collection systems and manholes are a vital component in every city's infrastructure. These systems are designed to transport wastewater from residential areas to treatment plants. Failure of sewer pipes due to traffic loads is brought about primarily by the cyclic live loads transferred to sewer pipes via manholes on paved road surfaces. The causes of sewer pipe failure include subsidence of the area around a manhole, loosening of sewer pipe joints caused by such subsidence, seepage due to such loosening, cavities caused by seepage induced runoff of sand, and collapse of the ground due to such cavities. The structural integrity of the concrete components is severely compromised by corrosion. This erosion of the infrastructure by corrosion is causing a nationwide premature replacement of failed structures. Billions of dollars are being spent worldwide on the repair and maintenance of sewer systems and roads. Microbially-induced corrosion causes damage via micro-organisms. Deterioration is caused by acid excretion which etches the surface of concrete, penetrating the mortar surface, especially in sewer systems. The mechanisms of concrete and reinforcement deterioration in sewer environments and microbially-induced corrosion is discussed in detail in this paper. A comprehensive review is given of the role of hydrogen-sulphide and micro-organisms in the deterioration of concrete in sewer environments and of repair and rehabilitation measures, including the modification of the materials used in construction of sewer pipes; the coatings and the sewer treatments. A complete review of the microbial deterioration of concrete and its remedies is also included.

Keywords: wastewater, infrastructure, sewer system, induced corrosion, microbial deterioration

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1. Introduction

The corrosion phenomena is caused by both chemical and bacterial activity. The presence of the sulphur and the bacteria in the sewer, together with animal and plant wastes, is the main reason for the corrosion of concrete. Brick manholes have been replaced over the years because of concerns about infiltration and a realization that the mortar holding the bricks together is subjected to corrosion. The two major causes of internal corrosion in a sanitary sewer are:-

1. Conventional acid attack caused by industrial waste discharged directly into the sewer system.
2. Sulphide corrosion, hydrogen sulphide H_2S corrosion or sulphide attack.

Sulphide corrosion occurs above the sewage surface while low pH-value sewage will cause corrosion below the water line (Keneth and Karl, 1991 pp 57–59). Sulphate attack occurs when soils with high sulphate levels contact the concrete pipe structure and the deterioration is external. Sulphate attack does not occur inside the sewer structure or pipe. Sulphide corrosion starts when sulphate in the sewage is converted to sulphur. The most corrosive agent that leads to the rapid deterioration of concrete pipelines in sewers is H_2S. The aerobic bacteria present oxidizes the H_2S dissolved in the moisture to sulphuric acid H_2SO_4. The H_2S dissolves in moisture films on the exposed concrete surfaces where it undergoes oxidation by aerobic bacteria to H_2SO_4 which attacks the concrete surface (Frenayj. and Zilverber H., pp. 93–17). The corrosion process is caused by the reaction of the biogenic sulphuric acid with the cementitious material of the concrete, which leads to eventual structural failure. This step is characterized by the production of a corroding layer on the surface of the concrete. This layer consists of gypsum $CaSO_4$ of various hydration states and moisture. The thickness of this layer expands into the concrete as more and more acid is produced to react with the concrete. The formation of ettringite $3CaO.\ Al_2O_3.CaSO_4.\ 12H_2O$ or $3CaO.\ Al_2O_3.\ 3CaSO_4.\ 31H_2O$ during the acid reaction process is another fact of the problem. Ettringite is expansive and causes internal cracking and pitting, which provides a larger surface area for the chemical reaction to occur. This will also provide further sites of penetration of the acid into the concrete. The conversion of the concrete to gypsum and ettringite weakens the structural integrity of the concrete pipe. This reduces the load-bearing capacity of the concrete and can result in the eventual collapse of the sewer. The action of anaerobic bacteria in sulphur results in the H_2S.

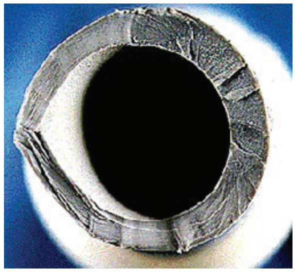
2. Failure of Manholes Constructed on the Roads

There are many kinds of manholes on residential streets, such as for water supply and drainage, sewage, telecommunication cable, traffic sign, electricity supply, etc. According to their applications, cast iron, polyethylene, or concrete is used as the material. Traditionally manhole is repaired by excavation, Manhole replacement, backfilling and then restoration of the site to its original condition. The manholes are sunk due to the road repair, which becomes the safety issue for pedestrians and drivers on uneven roads especially at night. Figures (1) and (2) show photos of several deteriorated manholes and sewer pipes constructed on the roads.

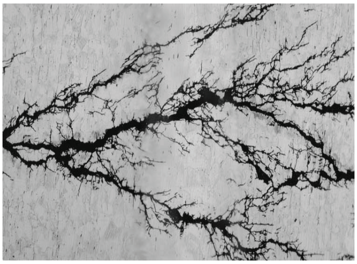
Figure 1: Failures in Manholes Constructed on the Roads.

Galvanic Corrosion.

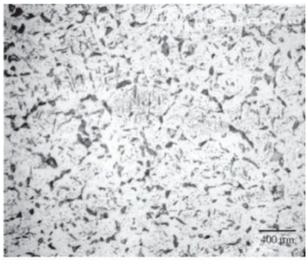
Corrosion Fatigue.



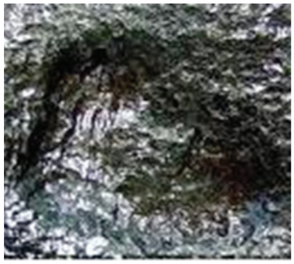
Fretting Corrosion



Stress Corrosion Cracking



Hydrogen Damage.



Concentration Cell Corrosion.

The Attack of Concrete Sewer Pipes

Corrosion of Prestressed Steel Cylinder Cement Pipes

Figure 2: Failures in Sewer Pipes Constructed on the Roads.

3. Manhole covers

Covers for manholes come in a wide variety of shapes, sizes and materials. Domestic driveways have the unattractive pre-cast concrete crown units and covers, and most block paved areas now feature recessed tray covers, fabricated from galvanized steel. Over recent years, covers manufactured from new high-strength composite materials have started to be used, primarily in pedestrian areas. Ductile and Cast Iron covers are manufactured to conform to BS EN124 but other materials, such as galvanized steel or pre-cast concrete are not included within the scope of that standard.

4. Causes of Deterioration of Concrete

Generally, H_2S gas dissolved in water is the most corrosive agent that leads to the rapid deterioration of concrete pipelines in sewers. The aerobic bacteria present oxidize the H_2S to produce H_2SO_4 (2). At normal domestic sewage pH-value varies from 1/4 to 1/3 of the dissolved sulphide exists as molecular H_2S, which is released to the air and deposited on the moist structure wall. Bacteria on the wall convert the H_2S to H_2SO_4, which reduces wall moisture pH-value to the 1 to 2 range, and the acid corrodes the structure wall above the flow line. A highly corrosive environment is created by the presence of volatile hydrocarbons and H_2S. Both concrete and steel are susceptible to accelerated corrosion rates under such conditions. Few researchers have discussed the methodology for carrying out experimental work to determine the corrosion rate, along with their main corrosion mechanism and the factors controlling the corrosion rate, and consequently there is a few of published papers in this area (Horlyckl. And Salome, pp. 71–77). Factors affecting increased sulphide in sewage are outlined below:-

1. High sewage temperature, accelerating the sulphate/ sulphide conversion process.
2. High biochemical-oxygen-demand (BOD) sewage, particularly high-soluble BOD sewage.
3. The low velocities lengthen detention time, and increase settling of organic solids, and grit in the sewer invert.
4. Long detention times in wet wells, force mains, inverted siphons or surcharging gravity sewers.
5. Steep slopes and high flow velocities.
6. Turbulence caused by inadequate or poor design of structures, such as junction structures with colliding flows, drop structures, intercepts or discharge above the wastewater surface in the main line.
7. Changes in slope that lead to hydraulic jumps, abrupt flow direction changes and short radius curves.

Other factors tend to increase the amount of H_2S escaping from the wastewater. H_2S is released primarily as a gas and will spread in the air. When released as a gas, it will form sulphur dioxide and H_2SO_4 in the atmosphere. Sulphur dioxide, a major component in acid rain, can be broken down further and accelerates corrosion rates. H_2S remains in the atmosphere for approximately 18 h. In some instances, it may be released as a liquid waste from an industrial facility. Beck

1994, studied the cause of concrete sewer pipe corrosion. The objectives of the project were to compare the cost for routine cleaning of interceptors and the accumulative corrosive effects that excessive deposition have on sewer pipes. Manhole locations were set up and data were collected from them for pipe wall deterioration and deposition, throughout 3660 m (1.1 m and 0.76 m in diameter) concrete interceptor. Sewer sediment is a type of settle-able particulate and form bed deposit. It has been established that excessive pipe deterioration and an excessive amount of deposition existed in the upstream half of the interceptor and low amounts of deposition and minor deterioration were present in the lower half. Jahanif et.al. 2001, studied the degradation of a mortar specimen exposed to an acidic sulphate solution. The pH-value of the test solution was maintained in the range (4 to 5) for eight days and (2 to 3) for 73 days. By using the experimental data, the role of the diffusion reaction in the deterioration of concrete surfaces was determined.

A study conducted by Cady and Richard 1990, showed that the affected area in an entrained air void system was the main reason for the deterioration caused by inadequacy of entrained air in these areas. Their examinations showed that the magnesium oxide MgO content of the Portland cement in the affected areas was 3.5 times more than that present in the unaffected areas. MgO (9.1%) was more than its permissible value prescribed as per ASTM C-150. Ramachandran,1981 stated that dead burnt magnesia expands some 17%. This was in the context of the slow hydration of unreactive material requiring additional water for hydration over the original mix water. The volume changes with reactive magnesia as it hydrates in the cement matrix containing Portland cement and can be engineered to be neutral. It has been generally accepted that concrete corrosion is caused by bacterial oxidation of H_2S in sewer systems. Costs related to sewer replacement and remedies are quite high, but there is limited knowledge and documentation on the relationship between H_2S levels and corrosion rates. This information is necessary in order to select the appropriate means of H_2S control and to conduct a cost–benefit analysis. The effect of the wastewater composition on corrosion damages in the sewer pipelines was considered, especially for the steel and cast iron pipes. The concrete pipes are alsosusceptible to corrosion damage, especially in the presence of H_2S and/or fatty acids (Didenko et.al. 2002 pp33–35).

3. Role of Micro-Organism in Deterioration of Concrete in Sewer Pipelines

Sulphur-oxidizing bacteria, combined with the bacteria of the acidiphilium genus, are the main agents of concrete corrosion in sanitary sewers (Aso, et.al.

2002 pp2636–2642) .Acidophilic iron oxidizing bacteria are responsible for the corrosion of reinforcement. They attack steel to convert ferrous to ferric oxide and, along with the sulphur-oxidizing bacteria, lead to the corrosion of concrete in many sewers. When the concrete members were exposed to a sewer environment containing H_2S of more than 600 (ppm), the pH-value of the concrete members reduced from an initial high value (of about 12–13) to a very low value (of about 2). This reduction in pH-value is attributed to the fact that sulphur-oxidizing bacteria grow on the surface of the concrete members, which converts the H_2S to H_2SO_4. The reduction in pH-value also takes place internally where bacterial growth is absent. This may be attributed to the penetration of H_2SO_4 into these areas. Formates, such as calcium formate, inhibited the growth of sulphur-oxidizing bacteria and iron-oxidizing bacteria when present in concentrations of more than 50 (ppm) (Hernandez, et.al. 2002 pp271–276). The main species of acid-producing bacteria in sewers is thiobacillus supported by acidiphilium. Babushkin et al.1997, and Davis et al. 1998, have elaborately studied the mechanism of chemical and biochemical processes taking place in sewage.

The alkaline nature of concrete with a pH-value of around (11 to 13) creates an unfavorable condition for the growth of micro-organisms-(Islander, et.al. 1991, pp 751–770). The presence of CO_2 and H_2S brings acidic properties to the concert (Lea F., 1970). The detrimental effects of CO_2 on concrete were studied by Ismail, et.al.1993, their experiments showed that atmospheric CO_2 reduces the pH-value of concrete to 9.5. A drastic reduction in pH-value was observed at an atmosphere containing 5000 (ppm) of CO_2. The theory behind this pH-value reduction was studied by Thistlethwayte and Goleb, 1972. Bacteria of the thiobacillus species stick to the concrete surface and, if adequate nutrients moisture and oxygen are available, begin to reproduce once the pH-value of the solution is reduced to approximately 9 (Mori T., 1992, pp29–37). The corrosion is predominantly caused by diffusion of sulphate into sound concrete beyond the gypsum-rich layers. Investigations show that the highest rate of attack of concrete by H_2SO_4 is 3 (mm per year) (Van Mechelan, and Polder, 1997 pp. 511–524) which may vary depending on the porosity (n %) and permeability (k) of concrete members.

4. Chemistry behind H_2S attack

Bacteria reduce the sulphur-containing organic compounds and sulphate to form sulphide. As a result of this property, septicity arises in the biowastes from the activity of the bacteria under anaerobic conditions. A part of the sulphur, after reduction, is released into a large percentage of sulphide ions into the environment, and a part is released as free H_2S. Proteolytic bacteria in the absence of oxygen act on the organic compounds of sulphur to form initially H_2S.

The H_2SO_4 formed is very corrosive to the concrete manholes and sewer pipelines. In addition to the above, the sulphate ions also attack the concrete directly thereby resulting in major corrosion. They also react with the calcium present in the cement to form gypsum, and with the calcium aluminum hydrate to form ettringite. In the above reactions, the formation of products causes a major increase in the volume of the cement and thereby leads to cracking and damage in the structure. The volume increase rate is 124% for gypsum and 227% for ettringite. There is a large increase in the stress on the surface of the cement. This is even further worsened by the fact that H_2S also attacks the concrete and the steel reinforcement. It reacts with lime to produce a soluble product as shown below:-

$$Ca(OH)_2 + 2H_2S \text{ --- } Ca(HS)_2 + 2H_2O$$

Ferrous sulphide is formed as a result of the H_2S reaction with the reinforcing steel through the cracks produced by sulphate attacks. Water and oxygen, also migrating through the cracks, form iron oxides and hydroxides. The products formed here also increase the volume of the concrete surface thereby leading to cracks and corrosion.

5. Preventing Concrete Deterioration

During the design of a wastewater system, the conditions that generate H_2S have to be reduced by the engineer. Excluding piping, approximately 40% of a wastewater system is made up of concrete structures; therefore, some means of reducing concrete corrosion must be utilized. It must be effective and economical. It can be achieved either by treatment of the sewer or the modification of the concrete. Concrete protection methods commonly used for structures include modifications of concrete mix, design, coatings painted or rolled onto the concrete surface, and liners that have integral locking projections cast into the concrete. Modifying the concrete mix usually involves increasing the alkalinity, since the corrosion rate is inversely related to concrete alkalinity. The following points are to be considered during the construction of sanitary works:-

1. Use of low alkali cement.
2. addition of micro silica to precast concrete sewer pipe doubles the

corrosion rate of conventional concrete pipe when exposed to acid

3. High-alumina cement increases corrosion rates at typical pH-value of (1 to 2) on structure walls.

6. Conclusions

The theory of microbial-induced concrete deterioration explains both the chemical and mechanical aspects of concrete. The suggestions of various researchers for modification of structures, composition of cement and biological activities taking place in sewers that lead to the deterioration of concrete are to be practiced. Suitable measures are to be adopted before installation of sewer pipelines, and treatment of sewage should be carried out for durability and performance of structure. Manholes should be provided at regular intervals, which can avoid damage. Odor impact assessment is an effective tool for the preparation of environmental management plans, development of appropriate regional and local planning and development control instruments and odor regulation. Odor impact areas should be plotted using nomograms of odor concentration corresponding to the same values for odor impact criteria. Suitable materials and design can be used to safeguard the structure from deterioration by sulphide attack from sewage. Repair work should be carried out at regular intervals to check the sedimentation layer formed in the sewer pipelines. This can prevent severe damage, that is, the collapse of the whole structure. The concrete can be protected by the followings:-

1. Prevention of corrosion of concrete.
2. Prevention of corrosion of reinforcement. Its characteristics are:-

- Altering the material used for the pipelines.
- Providing corrosion-resistant coatings.
- Providing cathodic protection.
- Modifying the engineering aspects of the structure.

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