THE STOPPING OF CRACKS INSIDE A REINFORCED CONCRETE PIPE AS A RESULT OF USING CATHODIC PROTECTION

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ABSTRACT

This paper shows how a certain secondary reaction resulting from cathodic protection, such as that caused by the reduction of oxygen leading to alkalinization, can be fundamental in the filling of fissures appearing in concrete. At first, several small trial tests were performed. Later, the results are applied on an industrial scale, with satisfactory results.

KEYWORDS

Cracks, pitting corrosion, carbonates, alkalinization, cathodic protection.

INTRODUCTION

Many pipes including reinforced and prestressed concrete, steel and cast iron, have an interior lined with a covering of mortar serving to insolate the steel from the aggressive environment surrounding it. Should this covering crack, and the fissure extend to the metal, a small anodic zone quickly forms which can lead to a process of pitting corrosion.
The liquid circulating through these pipes is usually fresh water for human consumption. The qualities of fresh water are quiet varied. If follows that ample mineral content is found; waters exist which vary from very hard to extraordinarily soft.

The chemical composition of the water is of great importance. If we are dealing with water of high bicarbonate (HCO_3^-) and Ca^{++} ions content, that is to say, of a clearly hard character, this can be of great interest with regards to its effect on the filling of fissures. The bicarbonates (HCO_3^-)can pass into carbonates, either due to the rising of the temperature or to the rising of the pH level. The chemical reaction is as follows (see eqn 1) :

$$Ca^{++} + 2\,HCO_3^- \text{ -------- } CaCO_3 + H_2O + CO_2 \qquad (1)$$

From this we see that the alkalinization process precipitates calcium carbonate. According to this and taking into account that the interior mortar covering can be more or less alkaline, calcium carbonate will be precipitated on the interior walls of the pipes in a somewhat random fashion, although not necessarily in the fissures, which in all probability will exist in areas of lower alkalinity.

Next, we are going to look at the action of cathodic protection in this process. As we now know, a process of reduction takes place at the cathode according to the reaction (see eqn 1):

$$2\,H_2O + O_2 + 4\,e^- \text{ ------- } 4\,OH^- \qquad (2)$$

If the potential is not very negative the preponderant reaction is the reduction of oxygen. More negative potentials or acid mediums will result in the reduction of hydrogen ions (H+). The reaction is as follows (see eqn 1):

$$2\,H^+ + 2\,e^- \text{ --------- } H_2 \qquad (3)$$

Both reactions lead to an alkalinization in the metal-solution interface.
This alkalinization, which is produced in cathodic zones, takes place in all metallic structures which we cause to act as cathodes in cathodic protection systems, as much in underground as in underwater systems (see eqn 2).
The importance of this alkalinization, which we can see as a secondary reaction of cathodic protection, will now be discussed in reference to the filling of fissures (see eqn 3).
If we apply a system of cathodic protection in pipe interiors, it will operate in the small anodic zones generated by the fissures. In the process of transformation into cathodic zones, an alkalinization will be produced which in fact would already protect the steel. But

moreover, if the water is scale producing, it will result in the precipitation of calcium carbonate which itself, in short time, will seal the fissures.

EXPERIMENTAL

Two pools of water were formed in a prestressed, plate-lined concrete pipe, one suffering pronounced internal fissures, and measuring two meters in diameter. The pools (P-1 and P-2) were separated by a distance of ten metres. Each pool was formed by the construction of a pair of metre-high walls placed at a distance of twelve metres, the resulting enclosure filled with water.
Almost immediately, it could be seen how the water which penetrated the cracks in the wet section seeped out through the fissures of the dry section. This result demonstrates that between the wall of the leak-tight steel liner and the cement lagging there is water penetration, which will generate corrosion and quite possibly its slippage. Observe how, in Figure 2, the water now emerges.

In P-1, a system of cathodic protection with magnesium sacrificial anodes and a current density of 0.25 mA/m^2 were put into place. Meanwhile, P-2 was left for observation with the objective of verifying if the water, on its own, was capable of sealing the fissures while at the same time continuing the evolution of corrosion. This was achieved through measures of potential.

In P-1, a steel sheet was put into place connected to the pipe, the purpose being to observe on it the activity of the cathodic protection. The water, being to observe on it the activity of the cathodic protection. The water, being of a scale-producing nature, was ideal for observing if this system could solve the problem.

RESULTS AND DISCUSSION

The tests lasted two months, during which time periodic measurements of potential were taken and observations made of the evolution of the fissures.

Table 1 shows us the potentials of P-1 with cathodic protection, while Table 2 shows the corresponding data of P-2, that which had no cathodic protection.

In P-1, with cathodic protection, within 24 hours, water had begun to emerge from the dry section and at 72 hours the drain was practically dry (FIG.3). Meanwhile, water continued to flow throughout the two months of the test in P-2, indicating that the water on its is not capable of sealing the fissures.

The tables show us four potential values at 3, 6, 9 and 12 metres. In the case of P-1, the measurement at 3m is closest to the anodes.

Table 1 shows us that the length of pipe with cathodic protection was well-protected, filling the fissures as had been theoretically foreseen. The steel sheet, which had been connected to the pipe, appeared without corrosion and with a good calcareous covering.

It should be emphasized that had the water not been scale producing, the cathodic protection would still have fulfilled its task, since the raising of the Ph in the fissures would have maintained the steel passive as well as protected by reaching an adequate potential.

Looking at the results shown in Table 2, one can see that the steel is in a state of corrosion, a logical result since the water has not ceased escaping through the fissures of the dry section. Moreover, this water comes out impregnated with oxide, which has formed in the interior. This is a problematic process, since the oxide can form to such a volume as to destroy the covering. It can be seen that a scale producing character of the water, on its own, is not capable of solving the problem of fissures.

TABLE 1

P-1 protected, potentials in relation to Ag/AgCl reference electrode.

TIME (In days)	POTENTIAL (mV) 3 metres	POTENTIAL (mV) 6 metres	POTENTIAL (mV) 9 metres	POTENTIAL (mV) 12 metres
0	-1268	-984	-821	-748
2	-1282	-994	-828	-770
6	-1298	-984	-832	-784
9	-1320	-1007	-844	-786
13	-1300	-993	-850	-785
16	-1296	-992	-857	-789
20	-1319	-1024	-859	-789
23	-1297	-1018	-867	-786
26	-1307	-1030	-878	-789
30	-1305	-1034	-869	-787
34	-1321	-1052	-885	-790
37	-1315	-1068	-885	-790
40	-1323	-1061	-890	-798
44	-1326	-1057	-882	-794
50	-1335	-1066	-890	-798
53	-1325	-1060	-896	-792
56	-1322	-1075	-899	-798
64	-1333	-1084	-896	-795
72	-1337	-1088	-897	-792

TABLE 2

P-2, without cathodic protection, potentials in relation to Ag/AgCl reference electrode.

TIME (In days)	POTENTIAL (mV) 3 metres	POTENTIAL (mV) 6 metres	POTENTIAL (mV) 9 metres	POTENTIAL (mV) 12 metres
0	-547	-525	-526	-543
2	-576	-546	-547	-556
6	-593	-574	-564	-560
9	-600	-583	-568	-553
13	-627	-602	-588	-564
16	-606	-589	-567	-552
20	-610	-595	-570	-557
23	-604	-595	-568	-556
26	-614	-567	-574	-562
30	-609	-597	-574	-562
34	-602	-589	-570	-562
37	-600	-589	-570	-568
40	-599	-585	-570	-563
44	-604	-593	-574	-566
50	-598	-587	-564	-552
53	-605	-594	-576	-564
56	-605	-585	-566	-556
64	-611	-591	-568	-589
72	-608	-585	-568	-561

Noting the results obtained from the trial test, cathodic protection was applied to the interior of a 24 Km length of pipe, employing sacrificial anodes weighing 4 Kg per unit, crossed by a steel core protruding from both sides of the metallic magnesium cylinder. This steel core was bent at a straight angle and welded at the connections of the leak-tight steel liners to the pipes. The relation was of one anode per three pipes. The density of current protection was maintained at the same level as that of the trial test.

After the cathodic protection had functioned for two years, 4 pipes were extracted due to the unforeseen necessity of repairs. Taking advantage of this opportunity, the interior of the pipes was examined. As seen in Figure 4, all of the fissures were found to have been perfectly sealed. In those two years, the anodes had hardly suffered weight loss, (Fig.5) which is in relation to the average predicted life.

CONCLUSIONS

1- Fissuring of the interior covering of a pipe runs the risk of creating a process of corrosion by pitting, which can result in generalized corrosion and the unfastening of the covering.
2- It has been shown that water penetrates through the fissures and circulates through the interface of the metal and cement covering.
3- The composition of the water and the alkalinity of the cement are not sufficient for the filling or sealing of the fissures, since the calcium carbonate precipitates in a random manner over the alkaline surface of the mortar without necessarily forming in the fissures.
4- Independently of the composition of the water, cathodic protection definitely solves the problem, since it protects upon reaching a passive potential of –800 mV and a pH of between 10 and 11 precisely in the fissures. Moreover, if the water is scale producing, it seals the fissures by precipitating $CaCO_3$ in them.
5- Two years after application in a two metre diameter pipe, several of the pipes were unearthed due to repairs. All of the fissures were perfectly sealed. These results are in agreement with those obtained in the trial test.

6- The behaviour of the sacrificial magnesium anodes, and their weight loss, are in agreement with the previously estimated lifespan of around 20 years.

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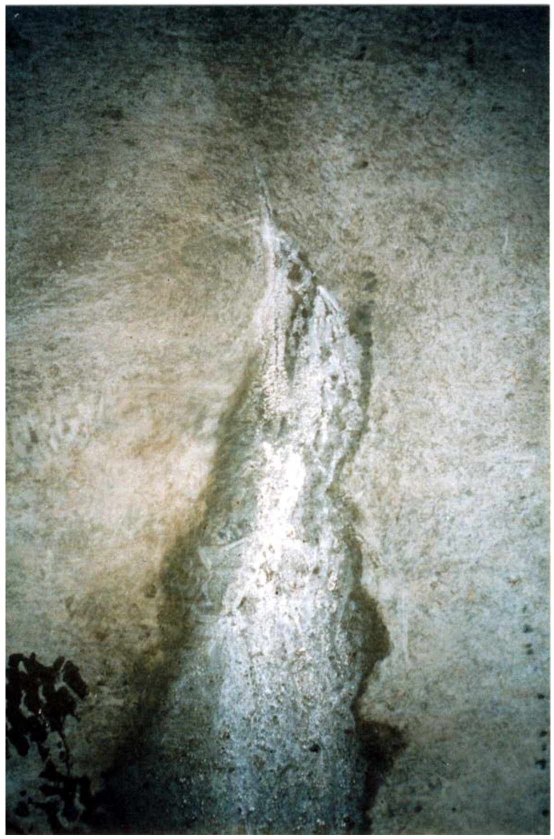

FIGURE 1- The drain was dry in P-1 after 72 hours

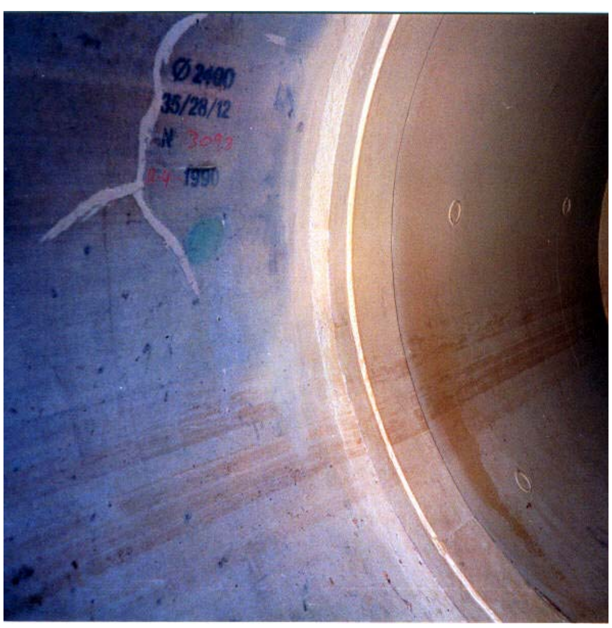

FIGURE 2- All the fissures were perfectly sealed