Concrete Pipe Association of Australasia Technical Paper

Concrete pipe exposed to acidic ground conditions or aggressive carbon dioxide

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ABSTRACT

Laboratory tests and records of field installations have been used to estimate the 100-year lives of concrete pipes exposed to ground conditions which are acidic or contain aggressive carbon diozide. Results confirm that the CPAA limits are appropriate though somewhat conservative.

The data and method of estimation also allow covers to be determined for pipes operating in conditions where the levels of aggressives are higher than the limits set in the CPAA table.

Key Words: acid resistance, carbon dioxide, concrete durability, concrete pipes, corrosion, groundwater, soils.

INTRODUCTION

Concrete pipes are used for a wide range of applications because they are capable of operating in various types of environments. The actual performance of the pipe will depend largely on the environment in which it is placed and the quality of the concrete. Most pipes are subject to noise underground conditions which can result in a continued strength gain but also makes them susceptible to attach from any aggressive agents that may be present in the groundwater.

Two of the more common aggressives are acids, which react with the cement at the concrete surface usually forming a soft paste, and aggressive carbon dioxide which dissolves the hydrated cement. When concrete pipes are placed in environments where aggressives like these are prevalent then the durability of concrete is a concern. As a guideline the CPAA has set limits for the use of unprotected concrete pipe in the presence of various aggressives agents (Ref 1). These guidelines are based on information relating to the performance of concrete pipes in various aggressive environments which has been collated by Humes Concrete R&D over the years. The information itself comes from long term tests set up to monitor the performance4 of concrete against particular aggressives in simulated and actual field conditions, exhumed pipes from known conditions, and testing that other organisations and authorities have performed. The information which has been obtained in these ways has been formed into a corrosive index where particular note is made of the exposure period, type of aggressives present, soil conditions and depth of corrosion, if any, for each example.

ESTIMATION OF LONG TERM CORROSION DEPTH

The CPAA limits are specified so that an unprotected pipe which is exposed to a particular aggressive in the groundwater with the minimum allowable cover according to AS 1342 of 10mm to the reinforcement will have a life expectancy of 100 years. To be able to determine whether these limits are in act reasonable requires some method of estimating the actual long term performance of concrete pipes in conditions similar to those listed in the CPAA recommendations from the relatively short term performance data that is available.

When concrete undergoes attack by an aggressive such as acid or dissolved carbon dioxide corrosion products are formed on the surface. If these corrosion products are removed it is reasonable to assume that the depth of attack is proportional to time. However, this is often not the case, as in many situations corrosion products remain adhered to the concrete surface. Should this occur the aggressives must firstly diffuse through the corrosion layer before further attack can take place. The corrosion layer, therefore, has the effect of slowing down the correction rate quite considerably. Information gained from previous testing performed at Westall R&D involving concrete beams exposed to both acidic and aggressive CO^2 environments without the removal

of corrosion products revealed that the time to reach a specific corrosion depth was proportional the the depth cubed or an even higher power (see Ref 2). The analysis involved using a method which related beam strength to corrosion depth. (See Appendix III).

Therefore taking the third power as a conservative estimate which will give the greatest corrosion depth gives the following relationship:

$t \propto d^3$

where t = time required to reach a specific corrosion depth, d

This can also be expressed as

$T = kd^3$

where k = a constant which depends on the aggressiveness of the environment

Using this relationship, it is possible to estimate the 100 year corrosion depth d100 once k has been determined. This is easily done by substituting in the available short term data and calculating k for each individual case.

RESULTS AND DISCUSSION

Graphs comparing estimated 100 year corrosion depths due to acific and aggressive CO^2 environments with the CPAA limits are contained in Appendix I. Appendix II lists the experimental data used for the esimates along with a worked example, while Appendix III shows how corrosion depth may be determined from beam strength.

A comparison of the CPAA limits with the case studies shows them to be consistent if not conservative for both the acidic and aggressive carbon dioxide environments. This is illustrated by the fact that all of the points plotted on both graphs which show estimates greater than 10mm in 100 years, correspond to higher levels of aggressives than the CPAA limits.

The limits specified for the various aggressives are split into three different categories according to their soil/terrain classification as indicated by the following table:

Soil/Terrain* Classification	Clay/Stagnant Groundwater	Medium	Sand/Free Flowing Groundwater
Aggressive Agents			
Acid pH, groundwater or soild extract (2:1 water to soil extract)	4.5	5.0	5.5
Aggressive CO^2 (Carbon Dioxide) ppm	150	50	15

* Clay/Stagnant: Heavy soil such as clay, with little or no groundwater movement.

Sandy and flowing: Permeable soil combined with significant flow rate of groundwater.

Medium: Intermediate between the above.

These limits are specified so that an unprotected concrete pipe placed in any of the mentioned soil conditions with 10mm cover should have a lift expectancy of 100 years. The lines drawn through the points in Figures 1 and 3 corresponding top the CPAA limits make the time for attack to reach any specified depth inversely proportional to the concentration of the aggressive. These lines correspond to the upper limit of corrosion

depth which may be expected for a range of levels of acidity and aggressive CO^2, for each soil classification. (It should be noted that these lines have not been derived from the plotted estimates and are in no way directly related to them). However, many of these points are in relative agreement although the extrapolated lines tend to be somewhat conservative in relation to the amount of cover needed as they predict a greater long term corrosion depth than the individual examples show.

This is indicated by the points relevant to each soil classification lying below the line. If these estimates were to be above, some adjustment of the line by altering the limit would be required to ensure a 100 year operational live expectancy of the pipe.

Some questions may be raised as to the validity of the relationship used to estimate long term corrosion depths from relatively short term data i.e. $t \propto d^3$. However, if the method of testing andcalculating used to determine this relationship is examined there is little or no evidence to suggest why this relationship should not be quite accurate. None of the assumptions are unreasonable, the relationship is based on monitored experimental data and the lowest power was chosen to give the maximum corrosion rate. It is also well known that the aggressive must first diffuse through the corrosion products if they are not removed, before further attack can take place which has the effect of progressively slowing down the corrosion rate.

Yet with internal attack, which is viewed as being equivalent to the most severe external corrosion conditions, the probability of the corrosion products being removed is also much greater. If this were to occur an increase in the corrosion rate would be expected.

One aspect which will affect the accuracy of these estimates is the data used. The longer a test has been in progress the more accurate the 100 year corrosion depth estimate will be. However, because of the cubic relationship used for the estimations a similar result can be reached using short term data even though the corrosion rate may not have been affected to any significant degree by a build up of corrosion products. For example, a concrete control pipe removed the pH 3.5 aggressive groundwater pool exhibited corrosion to a depth of 5mm after one year. Using this information gives an estimate of 32mm for the 100 year corrosion depth. After 3 years, the depth of corrosion had increased to 5mm, giving an estimate of 19mm which is not significantly different to the estimate after one year.

It should be noted that all the calculations performed were based on average corrosion depths and it is quite possible that in localised areas of the pipe surface the attack was more or less severe. The severity of attack depends on the percentage of time that groundwater is present and in fact the CPAA limits themselves are based on conditions which are wet for most the year. However, this was not the case with many of the cases listed in the corrosion index from which the data for the 100 year corrosion depth estimates were gained. Therefore increased corrosion could be expected in these cases if the conditions were to remain wet for a longer period of time, but as the limits specified by the CPAA already appear to be somewhat conservative this should not pose any problems.

Finally, points have been plotted according to either the pH or the level of aggressive CO^2, even though aggressive CO^2 and low pH sometimes occurred together. In cases where this was true the rate of attack due solely to the acidic conditions or the aggressive CO^2 would be less than the overall corrosion rate.

REFERENCES

1. PJ Roberts, 'The Corrosion and Corrosion Protection of Concrete Pipes'. Insert in Hume News, February 1986.
2. RC 8212 22/2/80, Concrete R&D - Corrosion Protection - Extension of the Life in Reinforced Concrete Products by Increased Cover to Reinforcement.

APPENDIX I

Figure 1. Estimated depth of attack due to acid

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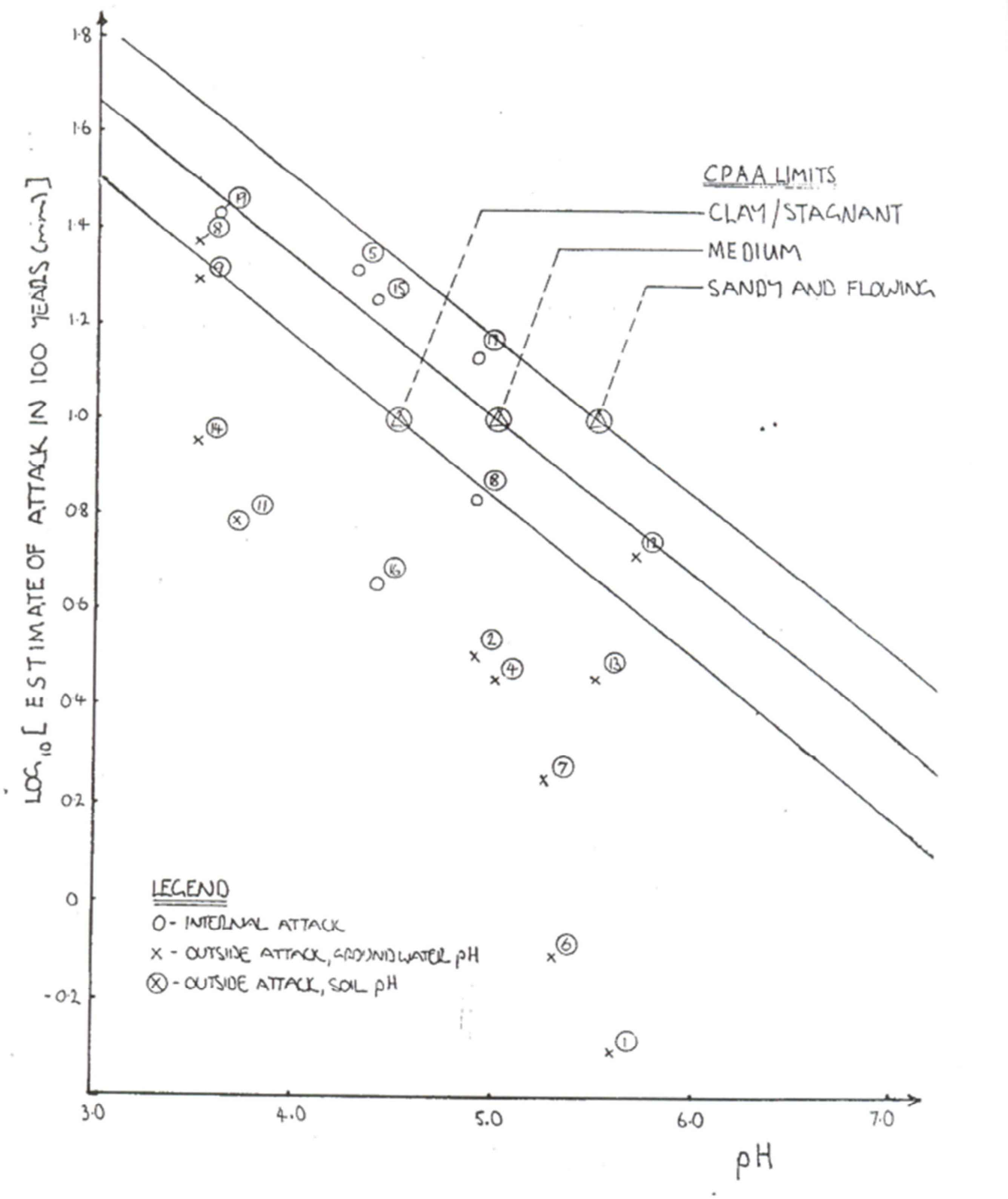

Note: the above graph is taken from the original reference document

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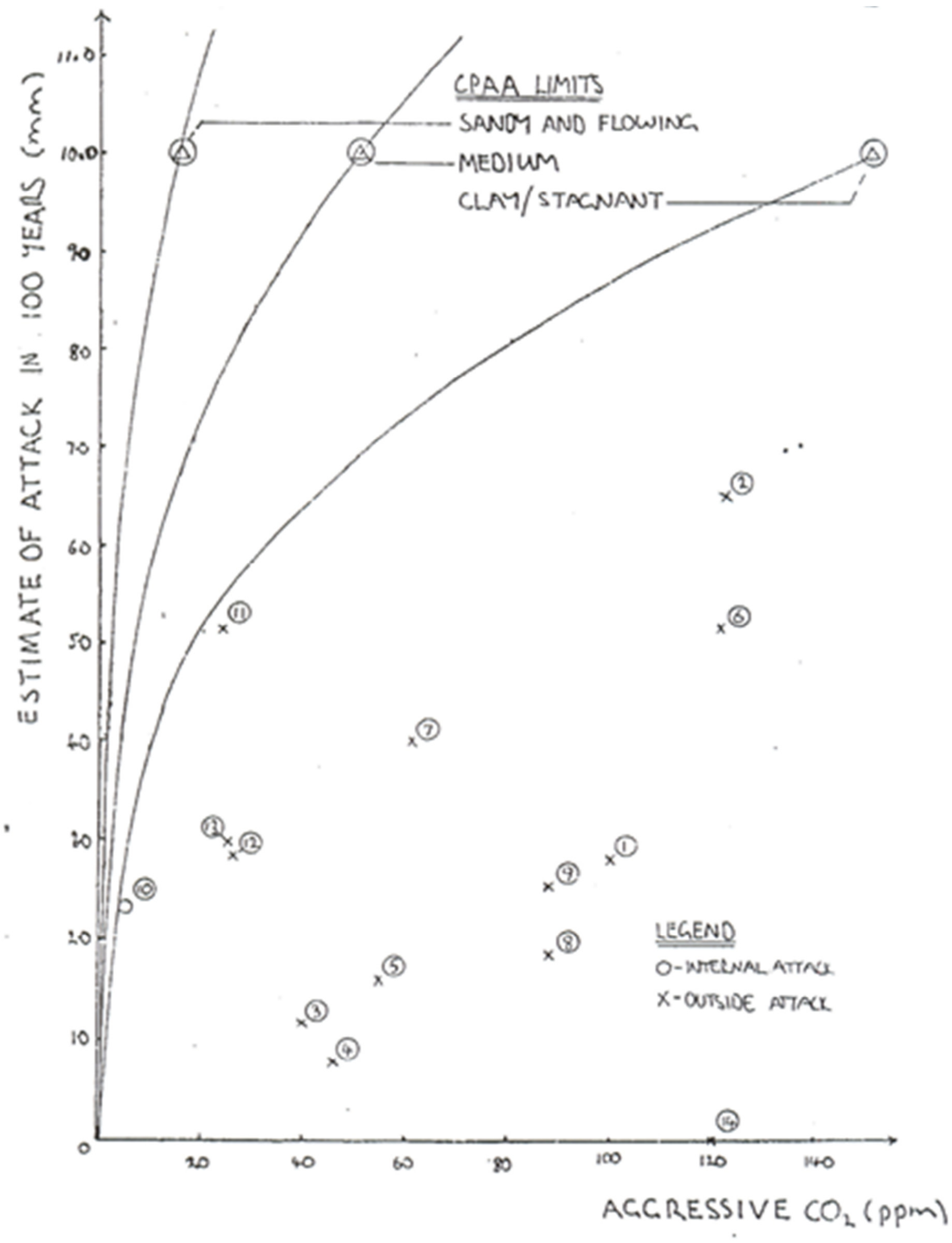
Figure 2. Estimated depth of attack due to aggressive CO²



Note: the above graph is taken from the original reference document

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APPENDIX II

Corrosion Data

(a) Attack due to acid

No.	Corrosion Index No.	pH	Length of Exposure (years)	Corrosion Depth (mm)	Corrosion Rate Constant, k	100-Year Corrosion Depth (mm)
1	1	5.6	30	0.33	834.8	0.49
2	2	4.9	10	1.5	2.96	3.23
3	4	5.9	10	-	-	-
4	5	5.0	10	1.3	4.55	2.8
5	8	4.3	5	7.6	0.0014	20.63
6	23	5.3	12	0.38	218.69	0.77
7	31	5.25	21	1.05	18.14	1.77
8	32	3.5	1	5	0.008	23.2
9	32	3.5	3	6	0/0139	19.3
10	39	5.0	1	-	-	-
11	62	3.7	19	3.5	0.443	6.09
12	63	5.7	2.5	1.5	0.741	5.12
13	63	5.5	3.25	0.9	4.458	2.82
14	66	3.5	6	3.5	0.14	8.94
15	*	4.4	2.7	5.32	0.0177	17.82
16	*	4.4	2.7	1.24	1.108	4.49
17	*	4.8	5	5.0	0.04	13.57
18	*	4.8	5	2.5	0.32	6.79
19	*	3.6	5	10.0	0.005	27.14

* Information obtained from the following reference:
C.A. Parker "*Comparison of the Chemical and Microbiological Durability of Asbestos Cement and Concrete Sewer Pipes under a variety of aggressive conditions*". 1969.

(b) Attack due to carbon dioxide

No.	Corrosion Index No.	Aggressive CO² (ppm)	Length of Exposure (years)	Corrosion Depth (mm)	Corrosion Rate Constant, k	100-Year Corrosion Depth (mm)
1	3	100	10	1.3	4.55	2.8
2	9	122	5	2.4	0.36	6.5
3	19	40	11	0.55	66.12	1.15
4	23	46	12	0.38	218.69	0.77
5	31	55	21	0.95	24.49	1.6
6	57	121	20	3.0	0.74	5.13
7	58	61	7.5	1.7	1.53	4.0
8	59	88	2	0.5	16	1.84
9	59	88	3.2	0.8	6.25	2.52
10	60	5	27	1.5	8	2.32
11	63	24	2.5	1.5	0.74	5.13
12	63	26	3.25	0.9	4.46	2.82
13	64	25	13	1.5	3.85	2.96
14	64	120	13	-	-	-

(c) Sample calculation of 100-year corrosion depth:

The following is a sample calculation demonstrating the method used to estimate the 100-year corrosion depth. The data are taken from Corrosion Index Card No. 2, Okaihau Experimental High Pressure Water Main.

Data:

pH 5.6
Period of exposure: 10 years
Corrosion depth: 1.5mm

$t = kd^3$

where:

t = time to reach a specific corrosion depth
d = corrosion depth
k = constant

Determine k:
$k = t/d^3 = 10/1.5^3 = 2.96$
i.e. $t = 2.96d^3$

calculate d100 (100 year corrosion depth):
$d100 = (t/2.96)^{1/3} = (100/2.96)^{1/3}$
$= 3.23mm$

APPENDIX III

Derivation of expression for determining average corrosion depth from beam strength

The stress in a rectangular beam is calculated from the following expression:

(1) $fa = W/6/b/d^2$

where:

fa = stress

w = applied load

b = sample width

d = sample depth

Let f1 be the strength of a beam after a period of immersion in water and f2 be the strength of a similar beam after immersion for the same period in an aqueous aggressive environment. Let b1 and d1 be the dimensions of the first beam and b2 and d2 be the dimensions of the unaffected cross-section of the second beam. f1 = f2 making

(2) $W1/6/bl/dl^2 = W2/6/b2/db^2$

The beams were of approximately square cross-section making b = d and simplifying (2) to

$W1/d1^3 = W2/d2^3$ or

(2) $W2/W1 = d2^3/d1^3$

Let de = depth of corrosion

From (2),

$W1/W2 = ((d1-2de)/d1)^3$

$(W2/W1)^{1/3} = (d1-2de)/d1$

(3) $de = d1/2(1-(W2/W1)^{1/3})$

Eqn. (3) was used in RC 8212 to calculate corrosion depths from the strengths of beams immersed in acid and aggressive CO^2 solutions.