TECHNICAL BRIEF

Concrete Pipe in Acid Sulfate Soil Conditions

Concrete Pipe Association
of Australasia

Concrete Pipe in Acid Sulfate Soil Conditions

There are widespread areas in Australia where the soil contains sulfur-bearing compounds (pyrites) able to react with oxygen and release sulfate in the form of sulfuric acid. Described as potential acid sulfate soils, these do not pose a threat to the environment or infrastructure while they remain undisturbed. However if oxygen gains access to the pyrites, for example in the course of a construction project, a conversion will take place resulting in actual instead of potential acid sulfate soil. The acid and sulfate released by the oxidation will persist for a period of time which depends on the amount and rate of natural water passing through the soil.

It is recognised that potential acid sulfate soils occur extensively on the eastern and northern coastline of Australia. This has become more of concern to the construction industry in recent years as infrastructure and development is taking place in regions containing these soils which were once avoided or not considered.

Concrete is susceptible to attack by actual acid sulfate soils. The acid component attacks the main constituents of hydrated cement, altering the compounds to a form which can no longer provide strength or protection to the reinforcement. Sulfate ions dissolved in water react with the tricalcium aluminate in hydrated cement and free lime, if any is present, to form compounds having a larger volume than those originally present. The reactions can have a disruptive effect, especially on weak concrete, causing it to expand, weaken and break down, thus exposing the steel reinforcement to corrosion activity.

It is generally accepted that for concrete to offer the highest resistance to acid or sulfate attack it requires the material to exhibit typical physical and chemical characteristics such as

- Low water/cement ratio
- Very low permeability
- High strength
- Dense concrete matrix

The CCAA Technical Note "Sulfate resisting concrete"[1] states *"that for fully buried concrete structures in saturated soils a sulfate resisting concrete can be achieved from Type SR cement at a cement content of 335 kg/m*^{3} *and a w/c ratio of 0.5. The AS 3600 specifications for concrete structures in*

TABLE 1

Concentration limits applicable to pipe with normal cover to reinforcement From AS/NZS 4058, Appendix E

Constituent	Soil classification (see Note 1)		
	Clay/stagnant	Medium	Sandy/flowing
Chloride (p.p.m Cl–) max.*			
Unreinforced concrete	No limit	No limit	No limit
Reinforced concrete (see Note 2)	20,000	20,000	20,000
Sulfate (p.p.m SO_4–) max.			
Type GP – general purpose type Portland cement	1 000	1 000	1 000
Type SR – sulfate resisting type Portland cement or equivalent	10,000	10,000	10,000
Acidity			
Acid (pH) (min.)*	4.5	5.0	5.5
Exchangeable soil acid (mL of 0.1 M NaOH consumed by 100 g air-dried soil, max.)	70	50	30
Aggressive CO_2 (p.p.m) max.*	150	50	15

* In groundwater or of soil extract (2:1 water to soil by mass)

NOTES:

1. The groupings used correspond to the classification adopted by AS 1726 as follows:
   (a) Clay/stagnant – Practically impervious (that is impervious soils, for example, homogeneous clays).
   (b) Medium – Poor drainage (for example, fine sands, organic and inorganic silt, mixtures of silt, sand and clay, glacial till, stratified clay).
   (c) Sandy/flowing – Good drainage (for example, clean gravel, sands, mixtures of sand and gravel).
2. Continuously submerged in sea or groundwater. The limit of 20,000 p.p.m. corresponds to the concentration of chloride in sea water. Fluctuating saline groundwater conditions to be treated as separate individual cases often requiring additional protection.

acid sulfate soils, based on minimum compressive strength and Type SR cement, is shown to produce adequate sulfate-resisting concrete for the exposure condition indicated. Alternatively, performance based specifications based on Type SR cement and a concrete with a limit on either water permeability or rapid sulfate permeability can be used."

This is considered acceptable for cast in-situ or precast buried concrete products such as piles and water retaining structures. However steel reinforced concrete pipe is manufactured in a vastly different manner to these buried elements, and needs to be considered taking into account the properties of the material achieved due to these processes and the performance criteria applied on it.

Steel reinforced concrete pipe manufactured to AS/NZS 4058 "Precast concrete pipe (pressure and non-pressure)" is expected to have a 100 year design life. Traditionally concrete pipe in Australia has been manufactured to performance based criteria for long term load capability and durability. The Standard specifies minimum cover requirements in typical underground environments, based on this performance criterion, and also includes guidelines for aggressive environments containing chlorides, sulfates, acids, and dissolved carbon dioxide. In this regard, Appendix E of AS/NZS 4058 provides guidance on what the maximum concentration of these aggressive contaminants must be in a broad grouping of soils, to allow the typical minimum cover recommended in the Standard. These limits are set out in Table 1. However, the Standard does not address the specific question of acid sulfate soils and what is recommended to ensure the long term durability of concrete pipe in these potentially aggressive conditions.

Sulfate resistance of concrete pipe

Typically, concrete pipe in Australia and New Zealand is associated with a high level of durability. The low water/cement ratio (< 0.4), high strength (> 60 MPa), and low water absorption (< 6%) of concrete pipes suggest a reasonable level of sulfate resistance is readily achievable. It is expected that moderately high levels of sulfate can be catered for by the use of any Type SR cement in concrete pipe mixes. The highest resistance is obtained when blended cement is used as this greatly reduces the amount of free lime in the matrix.

The threat of sulfate attack is based on analysis of groundwater or soil extract (2:1 water to soil by mass), together with the limits shown in Table 1. If the sulfate concentration exceeds 1000 ppm, a cement is required which qualifies as Type SR (in accordance with the definition in AS 3972). Wide-ranging test series, for example as reported in the CCAA publication "Sulfate-resisting concrete", have shown that the use of sulfate-resisting cement enables concrete to be produced which will withstand very high levels of sulfate. The results are consistent with testing carried out by the concrete pipe industry in Australia$^{2-4}$, leading to recommendations that levels up to 3000 ppm for any Type SR cement or up to 10,000 ppm for blended cement will not compromise the 100 year service life required by AS/NZS 4058. Such high levels of concentration are extremely rare in any natural environment, including acid sulfate soils.

In designing for a significant level of sulfate, the aim is simply to ensure that the pipe is made with concrete having an adequate resistance to sulfate at that level. The outcome is not influenced by the soil classification, whether clay/stagnant, medium or sandy/flowing, and does not affect the required depth of cover.

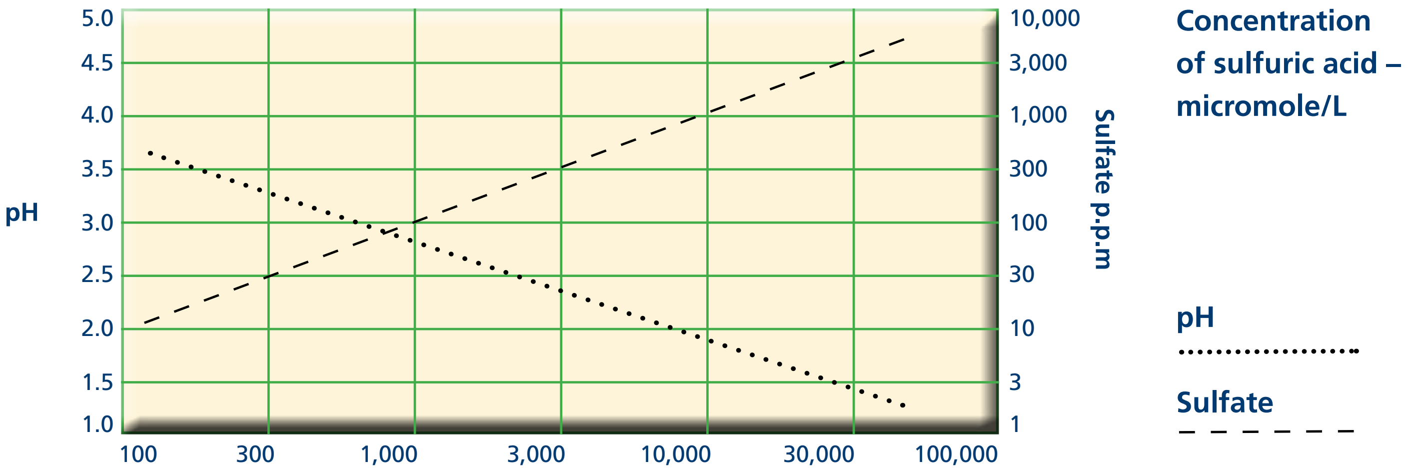
Resistance to acid

The pipe industry in Australia has also studied the effect of acid on concrete using data from the literature, together with field examples in Australasia and long term testing carried out in a laboratory environment, relevant specifically to concrete pipe of the quality required by AS/NZS 4058^{5}. Numerical data from the investigations were used to formulate the limits in Table 1, and also to enable the required cover to be determined for more severe conditions. If cover is adopted for "marine" exposure (ie 20 mm minimum instead of 10 mm), 100-year life is achieved with pH one unit lower than the limits set for normal exposure.

To obtain a perspective on the relative acid and sulfate effects from sulfuric acid, the levels of these two properties corresponding to varying concentrations of sulfuric acid in solution set out in Figure 1.

FIGURE 1

pH & sulfate content of sulfuric acid



The most acidic environment allowed for pipes with the increased cover is for the clay/stagnant condition, where the lower limit of pH is then 3.5. Referring to Figure 1, the sulfate level in sulfuric acid solution at pH 3.5 is between 10 and 30 p.p.m. – more than an order of magnitude lower than the concentration requiring the use of Type SR cement. At the lowest concentration of sulfate which would require Type SR cement (1,000 p.p.m.), the pH is less than 2, which would by itself rapidly destroy any unprotected concrete.

Sulfate may be present in soil from other causes than oxidation of pyrites. However where the predominant influence on sulfate content and pH is derived from oxidation of pyrites, attack by acid will far outweigh any concern about the effect of the sulfate constituent.

In the analysis of soil having potential for conversion to acid sulfate, samples are treated with hydrogen peroxide, to simulate atmospheric oxidation when soil is disturbed. This can result in very low values of pH, raising a question as to how relevant such pH values are to the condition which the pipeline will be subject to throughout its life. In interpreting such values it is relevant that:

- In practice the oxidation may not be as severe as that engendered by hydrogen peroxide.
- The acidity will diminish with time and highly acid conditions may in fact last only for a small fraction of the design life of the pipeline.
- With sulfuric acid the product of reaction with cement, calcium sulfate, is insoluble and will inhibit further penetration of acid.

No numerical values can be applied to these effects. It is suggested however that due allowance for them should be made by adopting a pH value 0.5 to 1.0 units above that resulting from the peroxide treatment, for the purpose of estimating the required cover as described.

External coatings

As an alternative to sacrificial concrete, or where the required depth is beyond the practical limit, the external surface of concrete pipe can be protected by an applied coating of epoxy or similarly acid resistant material. The external surface of the pipe must be clean and uniform enough to allow a continuous film to be formed, but no other preparation is required. Two or more coats are applied to give a minimum dry film thickness of 0.2 mm.

NOTE:

Coating materials are not all equally effective. Epoxy paint with a high solvent level is found to be less effective than solventless material. Very thin protective coatings can be expected to have only a cosmetic effect.

Summary – Recommendations

Sulfate resistance of concrete pipe, like typical concrete, is dependent on the physical and chemical resistance to the penetration of sulfate ions. The sulfate ions must penetrate the concrete and be concentrated by evaporation to cause disturbance.

Acid resistance is dependent on the cement matrix of the concrete and its ability to resist the formation of soluble calcium products that affect the surface.

Thus, in acid sulfate soils, the aggressiveness of the environment needs to be assessed separately for the effects of sulfate and acid. Tables 2 & 3 set out recommendations applicable to pipe manufactured in accordance with AS/NZS 4058 resulting in w/c ratio < 0.4 and water absorption < 6%.

TABLE 2
Concentration limits for sulfate component of soil or groundwater

Concentration – p.p.m. SO_4[1]	Cement Type	Note
< 1,000	Any	2
1,000 – 3,000	SR	3
3,000 – 10,000	SR, blended	4
> 10,000		5

NOTES:

1. In groundwater or soil extract (2:1 water to soil by mass).
2. Type GP or GB in accordance with AS 3972.
3. Type SR in accordance with AS 3972.
4. SCM in sufficient quantity to combine with free lime from the hydrated cement. An active fly ash at 20% of the blend is sufficient for this purpose.
5. Recommended that a protective coating such as a low-solvent epoxy be considered for long term protection

These limits are applicable for either normal or marine cover in accordance with AS/NZS 4058.

For acidity, adoption of marine cover allows the pH limits to be reduced, as set out in Table 3:

TABLE 3
Limits of pH for acid sulfate soil

Minimum cover per AS/NZS 4058 definition	pH limit for soil classification (see notes)		
	Clay/stagnant	Medium	Sandy/flowing
Normal	4.5	5.0	5.5
Marine	3.5	4.0	4.5

NOTES:

1. pH of groundwater or soil extract (2:1 water to soil by mass).
2. Soil classifications:
   - Clay/stagnant – Practically impervious (that is impervious soils, for example homogeneous clays).
   - Medium – Poor drainage (for example fine sands, organic and inorganic silt, mixtures of silt, sand and clay, glacial fill, stratified clay).
   - Sandy/flowing – Good drainage (for example clean gravel, sands, mixtures of and gravel).

In applying these limits, due allowance should be made for the effect of peroxide treatment of test samples, as explained above. Where the pH falls below the limiting value in Table 3, the pipe can be protected by a coating of low-solvent epoxy to minimum dry film thickness 0.2 mm.

Appendix – Long-term tests, resistance to sulfate and acid

Test 1 – Sulfate immersion test[2, 4]

CPAA member, Humes, conducted sulfate immersion tests on pipe concrete over a period of 24 years from 1972 to 1996. The tests were set up to determine the effect of strong sodium sulfate solutions (2,000 ppm and 10,000 ppm) on pipe concrete made using different cement types and blends.

The test involved cutting beam samples from non-reinforced concrete pipes made with Type A (general portland) cement, Type D (sulfate resisting) cement and blends using these cements along with fly ash or ground silica at 20% of the blend. Mixes that contained portland cement only as the binder had cement content 400 kg/m^3 while with the other mixes, counting the fly ash or ground silica as part of the cement, the content was 330 kg/m^3.

Pipes were steam cured for 3 hours as per typical manufacturing process, and the beams were cut with no further moist curing. Following this the initial flexural strengths were determined and samples immersed in the strong sulfate solutions. Samples were removed after various time intervals and flexural strengths determined.

The samples containing fly ash showed very little effect at the end of the exposure period. This result was better than that obtained in parallel tests using sulfate resisting cement but no fly ash; i.e. there was a significant benefit from removal of the free lime by the fly ash, beyond that obtainable just from a low level of tricalcium aluminate.

Test 2 – Exposure to acidic groundwater[5]

CPAA member, Humes, conducted over a 22 year period an experiment simulating pipe exposed to highly acidic groundwater. The experiment included uncoated pipe in conditions allowing free movement of groundwater, and less permeable types of backfill including clay. Several varieties of applied coatings were also included in the test.

For concrete pipes without coating or wrapping, backfills designed to inhibit movement of water at the pipe surface reduced the rate of attack. Even with heavy attack on the exterior of pipes, there was negligible effect on rubber ring joints.

The tests provided further confirmation that the advisory limits in the Standard of pH for concrete pipe with standard cover are appropriate.

REFERENCES

1. Sulfate-resisting Concrete, CCAA Technical Note 68, May 2011

2. Sulphate Immersion Tests on Spun Pipe Concrete, Humes Concrete, RC 1664i, 1989

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4. External Corrosion and Protection of Buried Concrete, Humes Concrete. RC 6905, 1977

5. Durability & Protection of Concrete Pipe in Acid Groundwater, CSR Humes Information Series NPD9901, 1999

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