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CONCRETE R & D - CORROSION PROTECTION

External Corrosion and Protection of Buried Concrete

SUMMARY

External attack on buried concrete results from the action of aggressive ground water. The most common aggressive agents in ground water are acids, carbon dioxide, sulphates, and chlorides. These substances are dangerous only if their concentrations exceed certain levels. Good quality concrete, in particular spun concrete, is more resistant to corrosion than poor concrete and requires protection only in exceptional circumstances. Sulphate resisting cement provides adequate protection against practically any natural sulphate condition, while paint coatings of suitable material, for example coal tar epoxy, are effective in protecting external concrete surfaces against any of the common aggressive agents.

There is a huge body of published data on the corrosion and protection of buried concrete but most of this refers to in-situ type concrete which is typically of poor quality compared with that of Humes products (particularly spun pipes). As a result, authorities and consultants throughout Australia tend to have differing opinions on the performance of concrete of high quality. Humes could promote the use of its concrete by

(a) establishing and monitoring a greater number of field test sites;

(b) deciding on the best method for protecting the joint area (interior of socket, exterior of spigot) of RRJ pipes. This region is particularly important as minimal corrosion could give leakage;

(c) seeking a wider range of opinions from authorities and consultants.

INTRODUCTION

In spite of numerous investigations extending over a long period of time, the subject of corrosion of concrete remains imprecise, and lacks a comprehensive theoretical basis from which firm conclusions can be drawn readily. Several authors have summarised various aspects (e.g. Refs. 1, 2, 3), and a number of specifications have been drawn up, recommending protective measures for particular conditions (e.g. Refs. 1, 2, 4, 5). A Technical Memorandum, CM9, covers the subject very broadly.

By and large, published information is based on experience with insitu-type concrete, which is typically of poorer quality than the concrete used by Humes (especially the concrete in spun pipes). As a result, recommended practice tends to be conservative, and opinions differ among authorities and consultants as to the conditions in which high quality concrete is satisfactory without protection.

Because the conclusions required in assessing a situation prior to installing a concrete structure are not drawn from basic or well-established principles it is usually necessary to take into account a wide range of relevant information. Furthermore, any conclusions are subject to alteration as new data come to light.

One of the best guides is local experience, which of course is not usually recorded as a publication.

This report deals with the corrosion and protection of buried concrete due to aggressive conditions prevailing at its exterior surface. Attack of this kind is due to aggressive ground water. If the concrete is dry, it does not deteriorate. The composition of ground water is governed by its past history as well as by the composition of the soil close to the concrete. For this reason, the soil composition adjacent to the concrete is not by itself an accurate guide to the composition of the ground water or to effects on the concrete. Soil composition can, however, give some indication of the properties to be expected of ground water, if any were present. For example, ground water in highly acid soil can be expected to be acid also, but not of the same pH value. (The pH value of ground water is commonly about one unit higher than that of soil at the same location, e.g. Ref. 6).

The most common aggressive components of ground water are acids, dissolved carbon dioxide (CO_2), sulphates and chlorides. Chlorides do not attack the concrete itself but are a potential hazard to the reinforcement. Other substances are of lesser concern in general but can be important in special circumstances (e.g. magnesium - see Ref. 3 p.128).

ACIDS AND CARBON DIOXIDE

1. Attack

1.1 General

These substances attack concrete by partly dissolving the cement. Except with poor quality concrete, attack progresses from the exposed surfaces, the concrete interior remaining virtually unaffected until the surface attack has progressed to it. One can therefore speak of a rate of attack expressed as depth per time interval, e.g. mm per 100 years. This rate depends on a number of factors - aggressiveness of the water itself, concrete quality, general ground conditions. These considerations are partly covered by a memo (Ref. 7 - copy attached).

1.2 Aggressiveness of water containing acid or CO_2

The aggressiveness of water containing dissolved CO_2 is usually characterised by the concentration of "aggressive CO_2", calculated from total "free" CO_2 and calcium (Ref. 1, pp.339 - 342). This is a measure of the amount of calcium which a given volume of the water will dissolve. To indicate the aggressiveness of water containing acids (other than carbonic acid which is CO_2 in solution), it is common to quote the pH value. Generally, higher pH values indicate reduced aggressiveness. However, pH does not reflect the aggressiveness of water directly because it is not a direct measure of the ability of the water to dissolve the calcium out of cement. For example, water of low pH will not dissolve calcium if the calcium salts of the particular acid or acids in it are insoluble.

Average rates of attack corresponding to levels of aggressive CO_2 or pH are given in Graphs 1 and 2. The points on these graphs are drawn from a number of sources, but there is no guarantee that further data would not result in significant variations in the position of the lines shown.

Because acids and CO_2 attack concrete in the same way, by dissolving calcium from the cement, the aggresiveness of a ground water could in principle be characterised accurately by the amount of calcium it is capable of dissolving. MMBW use this principle for classifying ground waters, expressing the result of a calcium solubility test as the equivalent ppm of CO_2. A test method is given in Ref. 4.

1.3 Effect of concrete quality

Concrete of such poor quality that water under the pressures prevailing in service percolates through it will obviously suffer much more rapid attack than concrete through which there is no general percolation. Water will not percolate through the walls of spun concrete sewer pipes under any operating conditions, nor is it likely to percolate through the walls of pre-cast products used for drainage (the drainage system itself keeps the head of water very low).

1.3 Effect of concrete quality (Contd.)

Even in the absence of sustained heads of water, concrete of good quality resists erosion better than poor quality concrete. The effect may be seen at the entry and discharge points of drainage lines, where the in-situ concrete will show significant erosion (e.g. to several millimetres depth) while the spun pipes of the line are not visibly affected at all. Poor quality pipes are affected much more rapidly than better ones (Ref. 1, pp.650 - 656).

With the spinning process, the combined effects of compaction and dewatering produce concrete having, at any specified A/C ratio, the greatest possible resistance to attack. Spun concrete was found to be superior to similar cast concrete in immersion tests (Ref.30) and a similar relationship has been found between spun and cast mortar (Hattersley and Welch, University of NSW, 1971). Another effect of the spinning process is to minimise the effect of A/C ratio - lean mix (8/1) spun concrete was attacked no more rapidly than richer mix (5/1) spun concrete in laboratory tests over three years (Ref. 8).

1.4 Effect of cement type

There are no discernible differences between the various types of portland cement (Ref. 2, p.22; Ref. 9). High alumina cement is more resistant than portland cement (Ref. 9, p.125; Ref. 1, pp. 525, 649; Ref. 2, p.78). (Some authorities do not agree with this).

With regard to the effect of pozzolan in concrete, there is some disparity in reports, but on the whole it appears that the effect is negligible. (Ref. 2, pp.269, 295; Ref. 9; Ref. 8; Ref.10).

2. Protection

2.1 Assessment of need for protection

No protective measures are required if the unprotected concrete structure can confidently be expected to have the life required of it. Just how soon the end of the useful life of a concrete structure comes about depends on the type of structure and the ground material in which it is embedded. For example, a concrete drain can sometimes continue to function long after the concrete pipes or culverts have deteriorated to a fraction of their design strengths. With box culverts and most sizes of pipes, there is negligible deterioration in strength until the reinforcement starts to corrode. As a conservative working rule, we can therefore take the time to failure as the time to remove the cover to reinforcement. Minimum specified cover varies with pipe diameter - cover down to 6 mm being allowed in some small sizes whereas at least 10 mm is required by the designs of medium and large pipes. Sewer pipe designs depend very much on the specifying authority, with cover ranging from 10 mm to 50 mm. Where there is a danger of corrosion, there is obviously a greater need to ensure that specified minimum cover requirements are in fact met.

2.1 Assessment of need for protection (Contd.)

The simplest way of estimating the pipe life is to read off Graph 1 or Graph 2 the time to remove cover from reinforcement of the pipe in question. This time can then be compared with the service requirement. Unless the expectation so obtained is very greatly in excess of the requirement this crude estimate would have to be refined in the light of other considerations (e.g. replenishment rate of aggressives), referred to in Section 1 and RC.6111.

2.2 Protective measures

2.2.1 Trench plugs

The backfill of a pipe or drainage line is usually less dense or less well compacted than the surrounding earth, and so enhances the flow of ground water along the line. This flow can be greatly reduced, particularly if the trench is cut through heavy, impermeable soil, or rock, by provision of trench plugs along the line. Trench plugs consist of walls of concrete or other, relatively impermeable material, such as bentonite, spaced at intervals along the line. The trench plugs surround and are in close contact with the pipes and, in addition, are recessed into the trench walls. Both SR & WSC, Victoria, and MMBW, have built pipelines with trench plugs.

2.2.2. Special Backfills

Special backfills can be designed either to reduce the flow of ground water past the concrete (e.g. clay) or to neutralise it (limed backfill). In the corrosion pool experiment, (Ref.11) clay in place of gravel backfill halved the rate of corrosion. Putting lime in the clay made no difference. This result is confirmed by Penhale (Ref. 6).

2.2.3 Sacrificial concrete

Extra concrete outside the reinforcement cage extends the nominal life in proportion to the extra cover provided. The cost to the customer of sacrificial concrete is highly variable depending on the original pipe design. Figures ranging from \$2 to \$5 per m^2 of external surface, for 25 mm of sacrificial concrete, are to be expected.

2.2.4 Calcareous aggregates

Calcium carbonate, which occurs naturally in a number of forms suitable for use as concrete aggregate is, like cement, soluble in acids and CO_2 solution. Calcareous aggregate in concrete is effective in reducing the rate of attack from the sulphuric acid generated in sewers from H_2S, by itself neutralising part of the acid. The rate of attack is reduced two to three times by substitution of calcareous for normal aggregates. In principle,

2.2.4 Calcareous aggregates (Contd.)

the same effect could be obtained with respect to aggressive ground water. As far as we know, such protection has never been specified. It is often difficult or expensive to obtain suitable calcareous aggregates at the location required, and calcareous sand is often of such poor shape and grading that spun pipe manufacture is made difficult. For these reasons, also because it is uncertain how effective the calcareous aggregates would be, other forms of protection are preferable.

2.2.5 Plastic film wrap

This protection consists in wrapping pipes in plastic film before backfilling. Its purpose is to reduce or eliminate the flow of aggressives past the pipe. The idea is that the small amount of aggressive material that comes into contact with the pipe initially is neutralised with negligible effect on the concrete, and that after that, replenishment is so slow that the corrosion rate is greatly reduced. It is not intended that the film should isolate the concrete from the ground water altogether. Overlapping edges of the film are not sealed together, and, of course, fortuitous holes in the film are to be expected.

Another function of the film is to keep the corrosion products in close ~~control~~ contact with the sound concrete, so that access of aggressives to it is reduced still further.

While, in principle, plastic film wrapping should be highly effective, there appears to be no direct evidence that it is and in an experiment (Ref. 11) it was not particularly so. It does appear to be effective in protecting cast iron pipes (Ref. 12), for which, however, the mechanism of corrosion is quite different from that of concrete.

Plastic film wrap is cheap, almost certainly cheaper than paint coatings, but in the direct comparison of Ref. 11 it was less effective.

2.2.6 Thin paint coatings

While thin paint coatings are ineffective in protecting concrete against H_2S attack, they offer effective protection against the typically milder conditions on the outside of buried concrete, and are widely used. Evidence relating to their effectiveness is summarised in a tender document (copy attached), which includes a specification for protecting concrete pipes. The extra cost to the customer of protected as opposed to unprotected pipes is typically 6$/$m^2$ of external surface. The

2.2.6 Thin paint coatings (Contd.)

external coatings experiment (Ref. 11) indicates that the inevitable small breaks in a coating, due for example to handling damage, do not seriously inhibit its effectiveness. Possibly, a multitude of small holes in a relatively small area would have a serious effect. Coatings which are virtually free of holes can be applied readily to the exterior surfaces of Humespun pipes. Cast concrete and Rocla pipes (which have a different surface texture) would present more difficulty.

It should be noted that in the attached specification for pipe coating, the joint surfaces are left uncoated. There are two reasons for this,

(a) the coating thickness could put the joint dimensions out of tolerance,

(b) rubber rings are inclined to skid rather than roll over the painted surfaces.

The interior of the joint is a dead pocket where corrosion is inhibited to some extent by difficult access for the aggressives. The rubber ring itself protects the concrete surfaces which actually make the seal. Results from the corrosion pool (Ref. 11) suggest that the enclosure of the joint surfaces does not, in fact, protect them to any great extent, so that the joint could possibly start to leak before there was any significant structural deterioration. Whether or not special measures are required to protect the joint, and, if so, what, are at present unresolved questions

The pipe coatings are applied either by roller or airless spray, either by Humes personnel or contact painters.

2.2.7 Thick coatings

It is appropriate to specify a thin paint coating for protection against practically any natural ground condition. In exceptional conditions, or where the ground is contaminated with corrosive industrial waste, a thick coating could be specified. Humes have no factory or field experience with such coatings. Applying them would be a specialist job - for which, however, there are specialist firms e.g. Ceilcote. Special provision would have to be made for the rubber ring joint surfaces (perhaps to the extent of providing a special joint design). The cost would be high - in excessof $\$10/m^2$.

2.2.8 Plastic sheet

This protection differs from film wrap in that the intention is to isolate the concrete altogether from ground water. The sheet is typically much thicker, to resist damage, and the edges of adjacent sheets are welded or otherwise sealed together. Plasticised PVC ("Plastiline") and butyl rubber have been used. Plasticised PVC is the cheaper of the two materials. Butyl rubber has a lower coefficient of permeability to certain materials but permeation through Plasticised PVC is negligible e.g.

(a) "Plastiline" is effective against H_2S which is the most severe form of acid attack to which concrete sewer pipe is ever likely to be exposed;

(b) carbon dioxide permeating through the film simply converts part of the concrete to calcium carbonate;

(c) (not strictly appropriate to this section).
Diffusion of sulphate and chloride ions is negligible (Ref.29).

To encase concrete sewer pipes in Plastiline by welding sheets together as the pipeline is laid, would cost the client in the vicinity of $\$30/m^2$. The exact figure would of course depend on the pipe diameter and field conditions.

SULPHATES

1. Attack

The mechanism of sulphate attack on concrete is quite different from that of acids and CO_2. Sulphate reacts with part of the hydrated cement, to form reaction products which are greater in volume than the reactants. Under suitable conditions, the effect is to disrupt the concrete. A fairly comprehensive account of sulphate attack on concrete is to be found in Ref. 3, pp. 127 - 136.

2. Protection

Attack is prevented if

(a) the concrete is sufficiently impermeable.
(see, for example, Ref. 13).
Impermeability limits the amount of sulphate which can penetrate. The reactive products have a further effect in reducing permeability (on account of their larger volume). With concrete of sufficiently low permeability one can therefore expect a reaction at or near the surface which prevents further penetration of the aggressive;

(b) the concrete is strong enough to resist the disruptive forces;

(c) the reactive substance in the cement (tri-calcium aluminate) comprises only a small proportion of the cement.

(a) and (b) operate effectively in well compacted concrete of low water cement ratio. With both low heat and sulphate resisting cement, the proportion of tri-calcium aluminate is limited by the cement specifications. It is marginally more expensive to use sulphate resisting in place of ordinary cement (the cement itself is more expensive, and separate handling procedures are required).

There is no general agreement as to the maximum level of sulphate which can be tolerated without recourse to sulphate resisting cement. Biczok (Ref. 2, pp 186, 187) quotes a number of sources, suggesting that sulphates become potentially dangerous at levels ranging from 100 to 1000 ppm. Because Humes concrete is consistently of high quality, it is justifiable to take 1000 ppm as the level above which sulphate resisting cement should be used.

Good quality concrete made with sulphate resisting cement will withstand very high levels of sulphate. Ref. 3, p. 132 cites results of 20 years of exposure of cast concrete specimens to water containing both sodium and magnesium sulphates, the sulphate content totalling 4%. Specimens made with sulphate resisting cements had suffered only minimal attack. In the sulphate exposure tests described in Ref. 8, spun concrete was found to be completely resistant to 1% sulphate solution over three years.

Additional protection is provided by paint coatings (Ref. 1 p.640). Conditions where a paint coating is required over good quality concrete made with sulphate resisting cement, in service underground, would be very rare indeed in most parts of the world. Under extreme conditions such as in the Middle East (Ref. 14), where salts are continually being concentrated by evaporation, the extra protection of a paint coating could be justified.

High alumina cement has a resistance to sulphates even greater than that of the best portland cements (Ref. 1 p.523).

CHLORIDES

1. Attack

1.1 General

Chloride ions do not attack concrete itself, but are a potential hazard to the reinforcement. In high concentrations of chloride, the alkaline environment provided by concrete is no longer effective in preventing corrosion of the steel. The effect is particularly marked with high-tensile steel, where chloride induces stress corrosion cracking at quite high levels of pH (Ref. 15). With mild steel reinforcement, high concentrations of chloride promote rusting. Rust formation then disrupts the surrounding concrete.

Chlorides are widespread in ground waters. In Australia, high concentrations are likely to be found near the sea, in ground periodically flooded by sea water. In regions where water evaporates very quickly from the soil (such as the Middle East- Ref.14), high chloride concentrations build up in the soil. These become dangerous when the soil is re-wet.

Evidence relating to the performance of reinforced concrete, including spun pipes, can be divided into two categories according to the concentration of chloride in water in contact with it

1.2 Chloride concentrations up to and including that found in sea water (about 2% chloride) - no further concentration by evaporation

Good quality cast reinforced concrete will last indefinitely provided cover in excess 12 mm is provided throughout (Ref. 3, pp. 136-138, Ref. 16, Ref. 1, pp.627-631). Spun concrete, with mixes as lean as 8/1, minimum cover, pre-cracked and kept under load as it would be in service, also suffers negligible attack (Ref. 17). These remarks do not apply to pre-stressed concrete, though pre-stressed pipes have been known to give adequate life in chloride conditions (Ref. 18).

1.3 Higher chloride concentrations

Concrete exposed to sea water in the tidal zone between high and low tides, where there is some daily concentration due to evaporation, is also durable (Ref. 3, pp.136-138, Ref. 1, p.627, Refs. 19,20), provided certain requirements are met with respect to concrete composition, quality, and cover to reinforcement.

Reinforced concrete, even spun concrete, provided with normal cover to reinforcement, is attacked quite quickly by saturated brine. (Ref. 21).

2. Protection

2.1 Chloride concentrations up to 3% in ground water

For both pipes and cast products

Ensure that minimum cover of 10 mm is maintained.

Cap all nibs and ensure that caps are not penetrated by reo. Do not use metal caps as these set up an electrolytic couple with the steel.

Do not use mixes leaner than 5/1 except for spun pipes.

Do not add chloride to the concrete during mixing (either in mixing water or as an additive).

These measures cannot be relied upon to protect pre-stressed concrete.

2.2 Chloride concentrations above 3% in ground water

Use rich mixes in both spun and cast concrete

Provide extra cover to reinforcement.

2.3 Conditions approaching saturation;
conditions favouring re-crystallisation of salts

Provide richest mixes and greatest cover to reinforcement consistent with other requirements. Take all possible steps to prevent evaporation of water from the surfaces of the pre-cast pipe or product e.g.

Paint coating, membrane wrap (Ref. 31)

Embedment in in-situ non-reinforced concrete, could be effective, although we have no reports to confirm this.

Galvanised reinforcement is of benefit (Ref. 20).

OPINIONS

Various authorities and consultants throughout Australia have their own ideas about corrosion and portection of concrete. Opinions of a number of these are given in Appendix 1.

CONCLUSIONS AND RECOMMENDATIONS

The main conclusions are set out in the summary. Most literature on corrosion of concrete relates to cast in-situ material of inferior quality to Humes concrete, particularly spun concrete, and so conclusions drawn from it tend to be conservative. While quite a number of examples relating to spun or other high quality concrete have been collected, a greater number would help in our efforts to persuade authorities and consultants to use Humes concrete in situations for which it is not currently accepted.

It is recommended that we

(a) take full advantage of any opportunities to extend our knowledge of performance of high quality concrete in potentially aggressive conditions;

(b) decide on a method for protecting rubber ring joints (supported by test data);

(c) seek the opinions of further authorities and consultants on the subject of concrete corrosion.

N. L. Harrison,
WESTALL LABORATORIES MANAGER

APPENDIX 1

OPINIONS ETC. OF AUTHORITIES AND CONSULTANTS

1. MMBW - Mr. G. Bryant

Use solubility of calcium carbonate as sole criterion for aggressiveness of ground water due to acid or CO_2. Rate of corrosion determined by many factors e.g. flow rate. Geological data used to predict this. MMBW classify ground water as non aggressive, highly aggressive, etc. but will not reveal to us their limits of $CaCO_3$ solubility for each classification. Believe both coatings and wrapping are effective against ground water, and that coatings must be free of damage or pinholes.

2. Mr. M. Simmonds, private consultant, Brisbane

Soil pH is irrelevant.

Classifies ground waters as highly aggressive etc. according to a diagram of his own based on one published by Lea.

His experience is tending to show that this classification is conservative. Simmonds diagram is in Ref. 22 (p.86). Believes both coatings and wrappings are effective protection. Favourite coating is coal tar epoxy (very impermeable).

3. PWD, Sydney

Messrs. Batty, Toh, McDonald.

Have drawn up their own criteria based on publications. See Ref. 23.

Unusual emphasis on soil composition (both pH and exchangeable acids) but acknowledge that pH of ground water is commonly $\frac{1}{2}$ to 1 Unit less than that of soil. Concrete with coal tar epoxy coating satisfactory for soil pH $>$ 4.5, SO_3 in soil less than 2000 ppm, SO_3 in water less than 700 ppm.

4. MWS & DB, Sydney

Mr. Lance Bowen.

MWS & DB coat sewer pipes to be put into areas with acid soil, with coal tar epoxy. Believed to be effective in soil of pH down to 3.5 - no records of failures of such pipes since practice was started in 1961.

5. Garlick and Stewart, Consultants

Mr. Mackay, Mr. Pearce.

Used to specify a coal tar coating similar to steel pipe type coal tar enamel for concrete sewer pipes in aggressive conditions. Most recent contract specified a thin coating - protection required was against ground water of pH down to 4.3, aggressive CO_2 up to 75 ppm.

6. B. W. Cherry, Monash University

Specified butyl rubber sheet for protection against CO_2 in ground water (believed to be several hundred ppm) on basis of low permeability of this material, for Victorian Arts Centre.

Works from text books etc. e.g. Biczok (Ref. 2). Concerned about concentrating effects from evaporation inside hollow concrete structures.

REFERENCES

1. F. M. Lea, "The chemistry of cement and concrete", Third edition, 1970. Arnold. Comprehensive reference book. Extensive and well-collated accounts of most aspects of concrete corrosion.

2. Imre Biczok, "Concrete corrosion, concrete protection", 1964 (Akademiai Kiado). General work on corrosion of concrete. Covers wide range, cites a wide range of sources, but material is not well organised.

3. ACI Monograph No. 4, "Durability of concrete construction", American Concrete Institute, 1968.

   Reference book covering chemical attack on concrete together with other aspects of concrete durability. Contains detailed sections on effects of sulphates and sea water. Very limited coverage of other types of chemical attack.

4. DIN 4030, "Evaluation of liquids, soils and gases aggressive to concrete" (Nov. 1969). This standard deals with most aspects of concrete corrosion, with explanations. Limits quoted are very conservative.

5. British Standard Code of Practice CP3, Chapter 9, (1950), "Durability". Sets limits for various types of concrete in sulphate ground water.

6. H. R. Penhale, "Corrosion of cement asbestos and concrete pipes in some New Zealand soils", N.Z. jnl. of science and technology, Vol. 38, 1956, p.257.

   10 year field experiment with concrete and AC pipes in various soil and ground water conditions.

7. RC.6111, 8-6-76, Concrete R & D, Corrosion protection, Resistance of concrete pipe to ground water attack - Criteria for PWD. Memo to Millar, Sydney. Mainly about acid and CO_2 attack. Discusses factors affecting rates of attack and recommends limits of pH and CO_2 concentration for standard concrete pipes.

8. RC.6265, 11-8-76, Concrete R & D, Investigations, Materials Utilisation, Durability of pozzolanic concrete, results at 36 months.

   Corrosion tests on pipe segments immersed in water, acid (pH down to 3.5), CO_2, 5/1 and 8/1 A/C mixes, some 8/1 with fly ash. No differences apparent.

9. D. G. Miller, P. W. Manson, "Durability of concretes and mortars in acid soils with particular reference to drain tile", Technical Bulletin 180, University of Minnesota Agricultural Experimental Station, June 1948. Concretes made from a range of portland cements and high alumina cement were exposed in acid soils of pH 4.1 and above for 20 years.

REFERENCES (Contd.)

9. (Contd.)

None of the 17 portland cements differed in resistance to soil acids. The concretes made with high alumina cements were slightly more resistant than those made with portland cements. None of the admixtures used in the tests improved the resistance of the concrete to acid soils. Mixes of high strength and low permeability gave the greatest resistance.

10. F. V. Doidge, "Pozzolana investigations, with special reference to acid attack", NZ Engineering, Dec. 15, 1957, pp.420 - 429.

Various effects of a pumice type pozzolan examined - resistance of concrete to acid attack apparently improved by the use of this pozzolan.

11. RC.6240, 13-7-76, Concrete R & D, Corrosion Protection, Corrosion pool - protection against ground water.

Concrete and AC pipe specimens, including rubber ring joints, buried in gravel or special backfills, with continuous circulation of acid solution pH 3.5. Some samples unprotected, some with paint coatings, some polythene wrap. Coatings chipped to simulate field damage. After 1 year's exposure, best protection was from coal tar epoxy.

12. W. Harry Smith, "Recent technological advances in the cast iron pipe industry", New England Water Works Assen, Vol. 84, No. 4, December 1970, pp. 339 - 360.

- use of polythene wraps for cast iron pipes.

13. G. L. Kalousek, L. C. Porter, E. M. Harboe "Past, present, and potential development of sulfate resisting concretes", Journal of Testing and Evaluation 4 , No. 5, Sept. 1976, pp.347 - 354. Emphasises the effect of low W/C ratio in providing resistance to sulphate attack. Some pozzolans also effective.

14. P. G. Fookes, L. Collis, "Cracking and the Middle East", Concrete, February 1976, pp.14 - 19.

- account of failures of concrete in the Middle East due to a range of factors, including effects of salts concentrated by evaporation.

15. K. F. McGuinn, J. R. Griffiths, "Stress corrosion cracking of cold drawn eutectoid steel wire", Third Tewskbury Symposium, 1974, pp. 274 - 285.

- Shows effect of chloride in raising the threshold pH for stress corrosion cracking of high tensile steel.

REFERENCES (Contd.)

16. "Concrete durability" - letter to the editor of "Concrete", December 1973.

Pontoons in tidal zone, Port Winston, France. After 30 years, no corrosion of reinforcement where cover exceeds 12 mm.

17. RC.6282, 9-9-76, Concrete R & D, Investigations, Materials Utilisation, Durability of pozzolanic concrete, reinforced rings, results at 36 months. Pre-cracked, pre-loaded lengths of spun pipe immersed in an acid/chloride solution (pH.5, Chloride 3%). A/C 5/1 and 8/1. No deterioration of reinforcement after 3 years' immersion.

18. G. E. Burnett, "Concrete pipe in high sulfate soils found in excellent condition after 34 years", ACI journal, Feb. 1974, pp. 80 - 81.

- cylinder type pre-stressed pipe in soil containing high chlorides and sulphates.

19. RC.5267, 9-5-74, Concrete R & D, Investigations, general, Townsville outfall sewer main.

Pressure pipe taken from service in an area subjected to periodic flooding by sea water, after 11 years. Negligible chloride penetration beyond outer surface layer. Some nibs corroded but spiral reinforcement unaffected.

20. RC.5148, 1-2-74, Concrete R & D, Corrosion Protection, Inspection of Werribee Sea Water test site.

Spun pipes of various compositions on the beach at Werribee, situated between levels of high and low tide. Generally a good condition after five years, particularly the rich mix pipe.

21. RC.4586, 21-11-72, Concrete R & D, Corrosion Protection, exposure of reinforced concrete pipes to saturated brine.

- deterioration evident in some samples after 13 months.

22. M. Simmonds, "Carbon dioxide in domestic water supplies. 3 Effect on steel; 4 effect on concrete". Proceedings of the society for water treatment and examination, Vol. 13, 1964, part 1, pp. 40 - 88.

23. RC.6319, 21-10-76, Staff, Travel, Visit to Sydney by Research Engineer G. Beale on 12-10-76.

24. RC.5030, 20-9-73, Concrete R & D, Corrosion protection, Inspection of pipeline at intersection of Klauer Sts. & Wells Rd., Frankston.

Carbonic acid 58 ppm, 20 ppm CaO,
Other aggressives negligible. Sandy soil. Slight surface etching after 11 years.

REFERENCES (Contd.)

25. Concrete pipe report, Lismore - letter to Humes from PWD Sydney, retained in RE-BE file B/15/1/2a.
Heavy soil, intermittent exposure only.

26. H. Granholm, "Ett longtidsprov pa Betongor", Transactions of Chalmers University of Technology, Gothenburg, Sweden, 1944.

Concrete test pipeline across a moor, test started 1932, finished 1944. Pipes of various qualities: hand tamped, machine pressed, spun. Ground water pH 4.5 - 6.5, ave. 5.3 for most of test. Aggressive CO_2 23-71 ppm, ave. 46 ppm. Heavy attack on poor quality concrete; very little attack on good (incl. spun) concrete at end of test.

27. C. D. Parker, "Comparison of the chemical and microbiological durability of asbestos cement and concrete sewer pipes under a variety of aggressive conditions" - Water Science Laboratories, April 1969.

Effect of various trade wastes (dairy, citrus, tomato) in concrete pipes.

28. R.C.4437, 20-7-72, Concrete R & D, Corrosion Protection, Drain in acid soil.

- 30 yr. old drain across Kew golf course. Heavy soil, probably dry for large proportions of the year. In places, soil pH down to 4.8. No attack on pipe.

29. RC.6255, 21-7-76, Concrete R & D, Developments, Plastiline, Diffusion of sulphate and chloride ions through Plastiline.

Describes diffusion test and gives 8 week results.

Most recent samples were taken at 8 months.

No diffused sulphate or chloride could be detected in these either.

30. RC.4578, 16-11-72, Concrete R & D, Corrosion Protection. Immersion tests on concrete of special cements.

31. "Effect of various substances on concrete and protective treatments, where required". Portland Cement Association Concrete Information, 1968.

c.c. GMCA/File
MCPA
Dr.Harrison ✓
Mr. Beale
TSM

SYDNEY (2)

ATTENTION: MR.J.MILLAR

NLH:LK:RC.6111
8th June 1976

JCM/ST:NCS 1432
8-1-76

CONCRETE R & D - CORROSION PROTECTION

Resistance of Concrete Pipe to Ground Water Attack - Criteria for PWD

Mr. Baker approached the Technical Committee of the Concrete Pipe Association and was advised that this committee could not consider the problem of ground water attack in pipes for at least six months. There is no guarantee that the committee could accept the problem even after that period; it is most likely that it could not. Reasonable progress can be made only if the PWD will co-operate directly with Humes.

Mr. Laughton asked that we recommend limits of ground conditions in which concrete could be used. He is aware that, for any set of measurable factors, the corrosion rate can cover a wide range, depending on qualitative factors. He is also aware of the distinction between inside and outside attack. Corresponding to any set of levels of aggressives in ground water, the rate for inside attack can be regarded as the upper limit of the rate for outside attack when all other conditions are particularly unfavourable. We regard a pipe as having failed when the reinforcement cover has been removed. To arrive at the most conservative limits satisfactory to concrete we therefore take the levels, from examples, at which inside attack would proceed at the rate of 10 mm per 50 years. These are:

for attack by acid - pH 5.3
" " " carbon dioxide - 40 ppm aggressive.

If the levels of aggressives in ground water are lower than the above, standard concrete pipes may be used without any further assessment of ground conditions. If they are higher, it is most likely that concrete will still be satisfactory but other aspects should be looked at. Desirably, Humes should be consulted so that an assessment can be made. This point can be emphasised by the indication, from our examples, that pipes with standard cover will last for fifty years on the average in ground water of pH 4.7 or 160 ppm of aggressive CO_2. The life can be extended by providing extra cover, in proportion to the thickness of cover provided, or extended indefinitely by coating. Factors apart from the levels of pH or aggressive carbon dioxide in the ground water which can be taken into account in making an assessment are listed in the appendix.

...2/-

The levels quoted above are based on the examples we have been able to collect so far and we are anxious to find or create more. Could the PWD nominate some sites in which test pipelines could usefully be installed?

We can tentatively accept the PWD contention that soil pH gives an indication of the pH of ground water should there be any present - that the ground water is likely to be higher in pH by ½ to 1 unit than the soil.

With regard to sulphate, examples suggest that spun concrete pipe made from sulphate resisting cement is resistant to any naturally occurring level of sulphate. We shall set up an experiment with a sample partly immersed in a sulphate solution to test whether partial immersion is particularly harmful (as was suggested as a possibility by Mr. McDonald).

Have we received the PWD report on the Lismore excavation yet?

N. L. Harrison,
WESTALL LABORATORIES MANAGER

APPENDIX

FACTORS OTHER THAN LEVELS OF AGGRESSIVES IN GROUND WATER THAT AFFECT THE RATE OF ATTACK ON CONCRETE PIPES

(a) Attack by acid

Factors which increase the rate of attack are

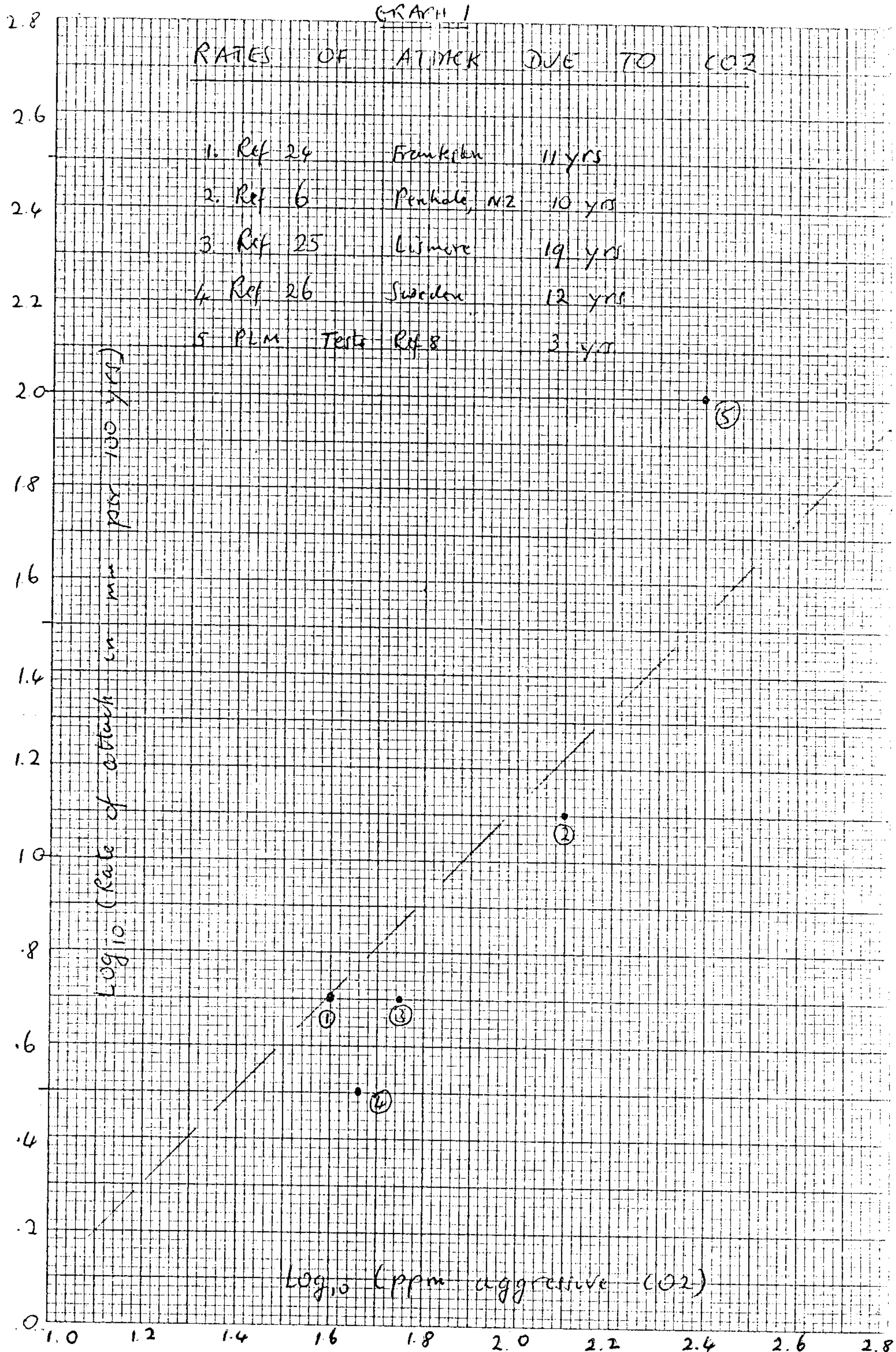
- continuously wet conditions
- steep gradients
- permeable (e.g. sandy) soil
- high levels of exchangeable acids in the soil. These must be exchangeable at pH levels which correspond to significant rates of attack. The methyl orange test (pH4) is therefore more relevant than the phenolphthalein test (pH 9)
- water soluble corrosion products; i.e. the calcium salt of the acid is water soluble.

The reverse decrease the rate of attack

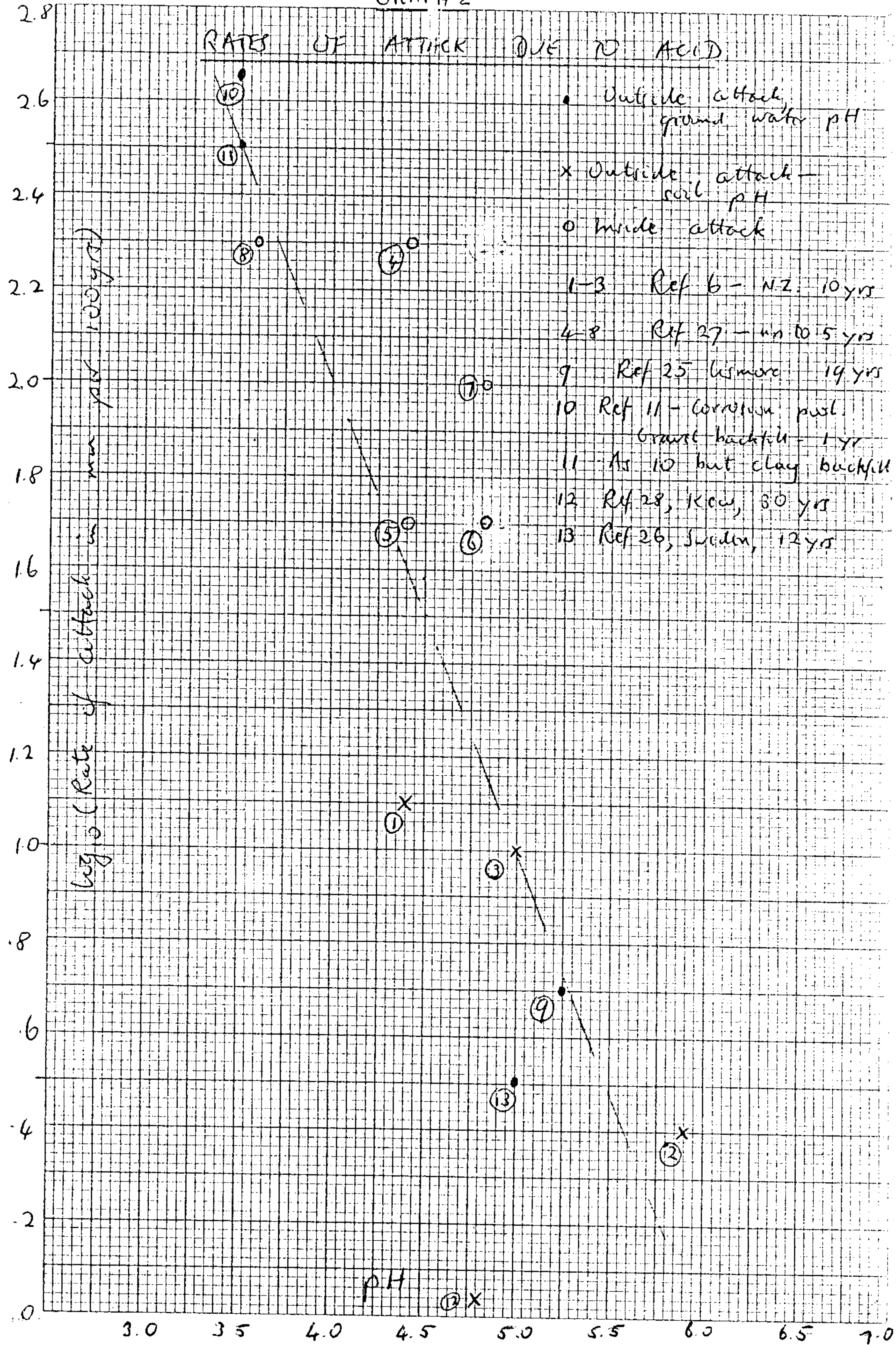
- infrequent exposure to ground water
- shallow gradients
- clay soil
- little exchangeable soil acid
- insoluble corrosion products.

(b) Attack by carbon dioxide

Considerations are the same as for attack by acids except that exchangeable soil acid is not relevant and the the corrosion product is always water soluble.


GRAPH 1
RATES OF ATTACK DUE TO CO2
1. Ref 24 Frankston 11 yrs
2. Ref 6 Penhale, NZ 10 yrs
3 Ref 25 Lismore 19 yrs
4 Ref 26 Sweden 12 yrs
5 PLM Tests Ref 8 3 yrs
Log10 (Rate of attack in mm per 100 yrs)
Log10 (ppm aggressive CO2)
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
1
2
3
4
5

GRAPH 2


RATES OF ATTACK DUE TO ACID
• Outside attack, ground water pH
x Outside attack – soil pH
o Inside attack
1-3 Ref 6 - N.Z. 10 yrs
4-8 Ref 27
9 Ref 25 Lismore 19 yrs
10 Ref 11 - Corrosion pool. Gravel backfill - 1 yr
11 As 10 but clay backfill
12 Ref 28, Kew, 60 yrs
13 Ref 26, Sweden, 12 yrs
log10 (Rate of attack in ... per 100 yrs)
pH
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
.0
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0

1975

D.S.A. TENDER

COMMENTS TO BE MADE ON EXTERNAL PROTECTION

(1) The protective system described in the specification is no longer possible to obtain as at least two of the materials called for are superseded and unavailable commercially. These are horizontal retort tar and tar impregnated hessian wrap. We cannot submit a tender for this protective system.

(2) The specified system was the one used for the protection of steel pipes some 25/30 years ago. This coating system has been improved by the use of a plasticised primer, coal tar enamel and asbestos/fibre glass reinforcement. If the Authority requires this type of coating we would transport the concrete pipes to Steel Mains at   and apply this material in accordance with steel pipe coating specification. (AS A126, 127 and CA 36-1965)

(3) We do not believe that the coal tar enamel or pitch coating is warranted by the exposure conditions and attach a proposed specification for coal tar epoxy coating (Appendix 1), which will give the required protection.

(4) We also attach as Appendix 2 our comments on the exposure conditions and our reasons for recommending coal tar epoxy coatings. You will observe that the coal tar epoxy formulation adopted has been proven in service. This is most important and we would not advise any change in material unless adequate service history can be established.

(5) We have not recommended polyethylene wrapping to cut down replenishment rates because we do not believe that there has been sufficient field experience with it in 900 and 975 mm diameter pipes. It would be an interesting development to do an experimental length with polywrap.

APPENDIX 1

PROPOSED SPECIFICATION FOR PROTECTION OF PIPES WITH COAL TAR EPOXY COATING

The coating shall be a coal tar epoxy paint - Vessey Chemical coal tar black oil epoxy paint and thinners or equivalent. The concrete pipe surface shall be clean and free from loosely adhering material; no surface preparation is required beyond what is necessary to ensure that this condition is maintained.

The paint shall be applied in two coats to give a total thickness of approximately 0.010 inch.

The paint coating shall cover all the outside surface of the pipe except the spigot end beyond the spigot step. The interior of the socket shall not be coated.

APPENDIX 2

COMMENTS ON EXPOSURE CONDITIONS AND REASONS FOR RECOMMENDATIONS OF COAL TAR EPOXY

While some of the groundwaters are aggressive to concrete, corrosion of pipes in even the most aggressive of them would not be rapid. MMBW recently installed concrete pipes (part of the South Eastern Outfall) in conditions of lower pH and higher aggressive CO_2 without any protection at all. For the proposed sewer, the prevailing conditions of (a) clayey soil, (b) absence of steep gradients, will slow down the replenishment of aggressives at the pipe surface, so that even without protection there is a good chance of adequate life. The life is extended indefinitely by a protective treatment which inhibits the replenishment of aggressives even further. Total isolation of the concrete surface (as is required for protection against H_2S attack) is not necessary. The usual alternatives for protection against ground water are coal tar epoxy (or similar) coatings or plastic wrap, to date used only for smaller sizes. There is a long history of successful use of coal tar epoxies, for example

(a) In the Brisbane area, the local government authority has specified this type of protection for over 20 years. Humes Ltd. in Queensland have supplied coated pipes for this purpose for this period,

(b) In Sydney, the MWS & DB have been using coal tar epoxy coating since 1961 for concrete sewer pipes in areas with pH down to 3.5. Originally, application of the coating was carried out by the Board but more recently Humes Ltd. have supplied coated pipes.

Both these authorities accept pipes coated as specified above. Leaving the spigot and socket surfaces uncoated is essential to enable the pipes to be joined (otherwise the ring skids rather than rolls). The uncoated surfaces left exposed to the soil are almost totally enclosed and are therefore in contact with stagnant water only, whose aggressiveness is rapidly exhausted. The coal tar formulation mentioned in our specification is the one accepted by the MWS & DB.

There are numerous references in literature to protection of concrete by paint coatings, but most are vague about the conditions against which the protection is required, and its effectiveness. One example is specific. Miller & Manson ("Durability of concretes and mortars in acid soils with particular reference to drain tile", University of Minnesota Agricultural Experiment Station, 1947) show an average strength loss of 20% in concrete cylinders buried in peats of various pH levels (4.1, 5.1, 5.4) for 17 years. Cylinders coated with bituminous paint or linseed oil and exposed under the same conditions for the same period did not lose strength.