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Deterioration, Repair and Maintenance of Reinforced Concrete Structures in the Cape Peninsula – Part 1

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Part 1 presents an assessment of the serviceability state of a number of reinforced concrete structures in the Cape Peninsula, from a durability perspective. It is shown that structures in a mild coastal exposure climate can manifest cracking and spalling at as little as 20 years on average after construction, while the corresponding figure for severe exposure is likely to be about 15 years on average.

Maintenance and repair options are dealt with, and typical repair costs are presented for structures in various deterioration categories. Repair costs increase very rapidly as deterioration proceeds, suggesting that repairs should be carried out as early as possible in the life of the structure.

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DETERIORATION, REPAIR AND MAINTENANCE OF REINFORCED CONCRETE STRUCTURES IN THE CAPE PENINSULA - PART 1

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ABSTRACT

Part 1 presents an assessment of the serviceability state of a number of reinforced concrete structures in the Cape Peninsula, from a durability perspective. It is shown that structures in a mild coastal exposure climate can manifest cracking and spalling at as little as 20 years on average after construction, while the corresponding figure for severe exposure is likely to be about 15 years on average. Maintenance and repair options are dealt with, and typical repair costs are presented for structures in various deterioration categories. Repair costs increase very rapidly as deterioration proceeds, suggesting that repairs should be carried out as early as possible in the life of a structure.

1. INTRODUCTION

Although reinforced concrete structures can be expected to show good durability, many structures in the Cape Peninsula area are currently experiencing deterioration caused primarily by reinforcement corrosion.

The underlying reasons may be identified as a lack of understanding of the corrosion mechanisms and inadequate specifications for achieving durable concrete at the design stage, poor workmanship at the construction stage, and a lack of knowledge and application of maintenance management strategies by owners of the structures[1]. The environment in the Cape Peninsula is one of high percentages of airborne chlorides, coupled with hot, dry and windy summers, and cool wet winters, all of which combine to create a harsh environment for reinforced concrete structures. It is becoming increasingly obvious that poor specifications and site practice have major implications for the durability of structures in this high risk climatic zone.

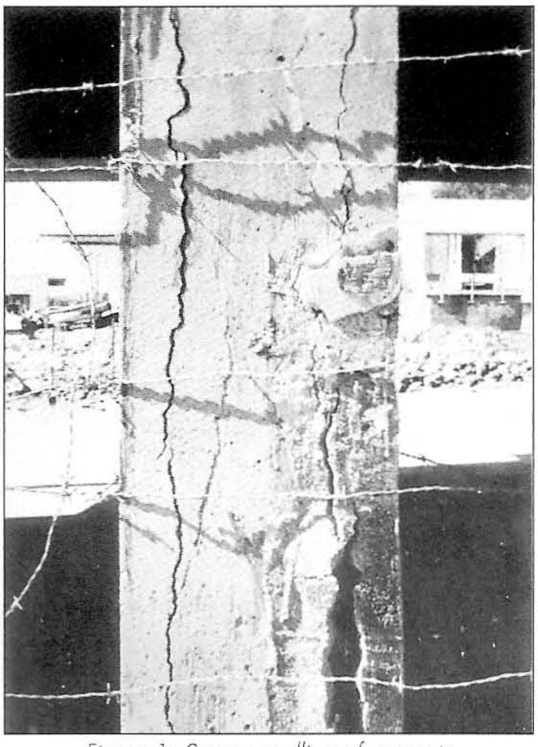

Figure 1: Severe spalling of concrete due to chloride-induced corrosion

Part 1 of the paper comprises an investigation into the rate at which reinforced concrete structures deteriorate in the Cape Peninsula due to reinforcement corrosion and what the accompanying repair costs are. Formulas are included to enable the calculation of future values of repair costs for budgeting purposes and also to enable the calculation of monthly/annual deposit amounts in order to save sufficient money for future maintenance at a specified date.

Part 2 of the paper (which will be published in the November issue) will comprise a discussion on aspects of decision models and life cycle costing for deteriorating reinforced concrete structures. This theory is then applied in the form of an example, in which it is attempted to establish the most economic point in the deterioration cycle to carry out periodic maintenance and repairs. From the results of the example, the importance of a planned preventative maintenance strategy is highlighted.

2. DETERIORATION OF REINFORCED CONCRETE STRUCTURES IN THE CAPE PENINSULA

2.1 Deterioration mechanism.

The deterioration mechanism that is considered in this paper is limited to the corrosion of reinforcement caused by the ingress of environmental chlorides only. The chloride ion (Cl^-) is particularly aggressive to steel reinforcement in concrete, causing pitting corrosion of the steel which in time may result in severe spalling of the concrete cover layer – see Figure 1. The corrosion mechanism is summarised in Figure 2 which shows that in chloride corrosion, pitting results from small anodic and large cathodic areas, which may cause substantial local loss of rebar section.

Current studies at the University of Cape Town are showing that chlorides can penetrate to the level of reinforcing steel and exceed a threshold concentration value within 5 – 10 years of first exposure in the Peninsula area, particularly where structures are exposed to wind-borne chlorides. With the high wind velocities in the area, chlorides can be carried many kilometres inland and penetrate concrete structures remote from the marine splash zone.[2]

2.2 Deterioration rates.

The factor exercising the greatest influence on the rate of concrete deterioration is the external environment i.e. the amount of chlorides in the air, or within the marine zone, which causes

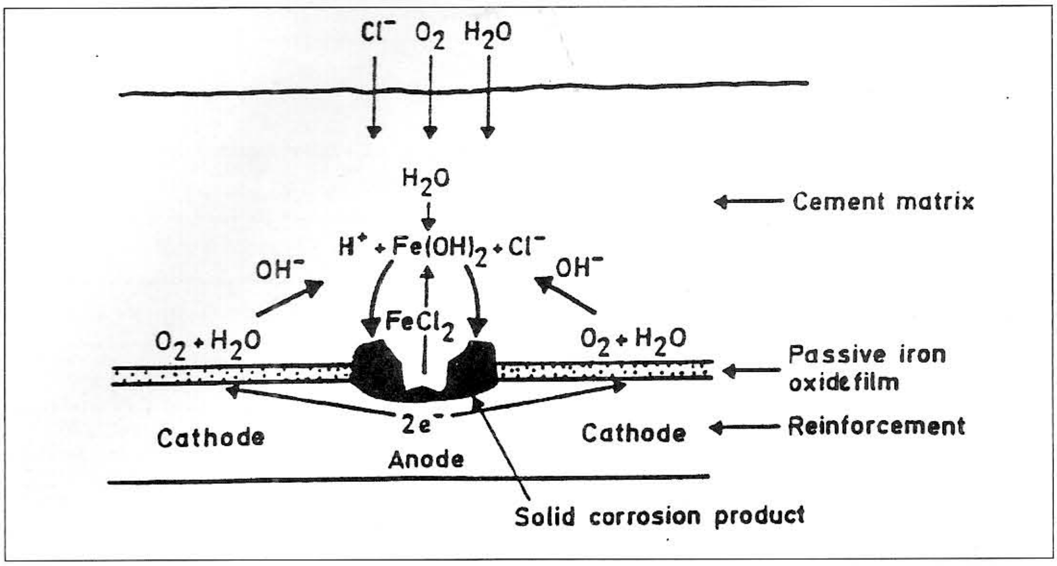

Figure 2: Corrosion mechanism for chloride corrosion of steel

concrete to deteriorate more rapidly than in a salt-free environment.

Other important factors are the cover to reinforcement, the strength of concrete used, the location of the element in the structure in question, and whether the structure has been painted/coated or repaired before.

Some parts of a structure deteriorate faster than others. Soffits tend to deteriorate faster mainly due to unfavourable moisture conditions, and lower cover to reinforcement. It is almost impossible to find structures that are subjected to exactly the same conditions and that consist of the same concrete. The development of a relationship between time and amount of deterioration is therefore a difficult task. This is discussed further below.

2.3 Assessment of existing reinforced concrete elements

Numerous structures were investigated in order to obtain an overall assessment of the rate of deterioration of reinforced concrete structures in the Peninsula (with one structure from Saldanha Bay also being assessed). The assessment involved a visual inspection and a search for information on the age, cover to reinforcement, design concrete strength and whether repainting or repair had been carried out. For some of the structures, recent tests for carbonation depth, chloride diffusion, oxygen permeability and porosity had been carried out and these results were also used to get a clearer picture of their current state. However, in general no testing was carried out to establish the depth to which chlorides or the carbonation front had penetrated the structure.

The visual assessment involved inspecting the reinforced concrete element or structure and rating it's sea-facing side holistically i.e. not only considering localised corrosion and spalling but considering the sea-facing side of the structure in its entirety. The sea-facing side was rated in order to provide better uniformity of the data collected. A short summary was made of each structure's current state and this data was then entered on a data sheet.

In order to categorise the extent of deterioration a classification system had to be used. The chosen classification system is one from the North Carolina Department of Roads in the United States, now also used in South Africa by the Department of Transport in their Bridge Maintenance Management software package.[3] The classification system was modified slightly so as to classify reinforced concrete elements that are not subjected to such great loads as bridges. The classification system used is shown in **Table 1**, indicating 10 categories, each representing a degree of deterioration, varying from *"no deterioration"* (category 9) to a *"replace-only"* solution (category 0).

The structures were separated into two categories, relating to either mild or severe coastal exposure environments. Structures within 200 m from the sea or in the sea were classified as being in a severe environment, and structures further away were classified as being in a mild environment. An attempt was also made to avoid, as far as possible, structures that had previously been painted or repaired so as to limit the amount of uncertainty. This collected data was then plotted for the different exposure zones and curves were drawn which give an indication of deterioration trends in the Cape Peninsula.

Table 1: Deterioration classification system

RATING		CRITERIA AND GUIDELINES
9	Excellent	New Condition
8	Very Good	Minor shrinkage or temperature cracks
7	Good	Non-structural cracks, light spalling, no rust stains visible through cracks yet.
6	Satisfactory	More significant non-structural cracks, moderate spalling, no rust stains visible.
5	Fair	Some section loss due to minor spalling, scour, etc. Structural cracks with light rust staining.
4	Marginal	More general section loss due to deterioration, spalling, scour, etc. Structural cracks with moderate rust staining visible.
3	Poor	Advanced deterioration, spalling or scour exposing reinforcing steel. Structural cracks with severe rust staining.
2	Very poor	Significant structural cracks. Re-bar exposed or rusted.
1	Critical	In-depth study required to decide whether to repair/replace.
0	Beyond repair	Replace is the only reasonable solution.

Due to the fact that often insufficient information was available regarding the cover to reinforcement, design concrete strengths and water/cement ratios to make corrections to points on the curve, it was decided to ignore correction factors and plot age versus deterioration based on a visual assessment only.

The two deterioration curves drawn from the data are shown in **Figures 3 & 4.** The dotted lines indicate extremes and the short-dashed line indicates a trend. The long-dashed line represents a possible trend for younger structures.

The younger structures in a mild coastal exposure climate begin cracking and spalling significantly at an average age of 20 – 25 years, and those in a severe exposure climate at about 15 years. It is also clear that structures in a severe exposure climate deteriorate much faster than those in a mild exposure climate, taking about 30 years to approach a stage of maximum acceptable deterioration. An interesting aspect of the two curves is that there are older structures in both of the exposure zones that show remarkable longevity. For example, from

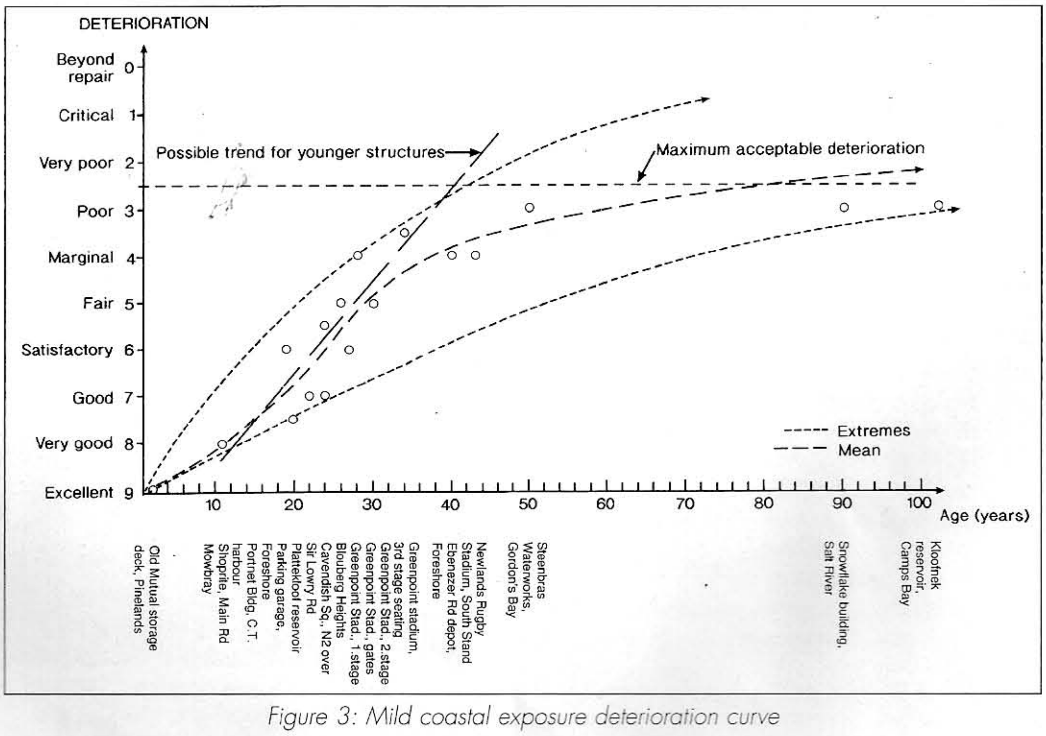

Figure 3: Mild coastal exposure deterioration curve

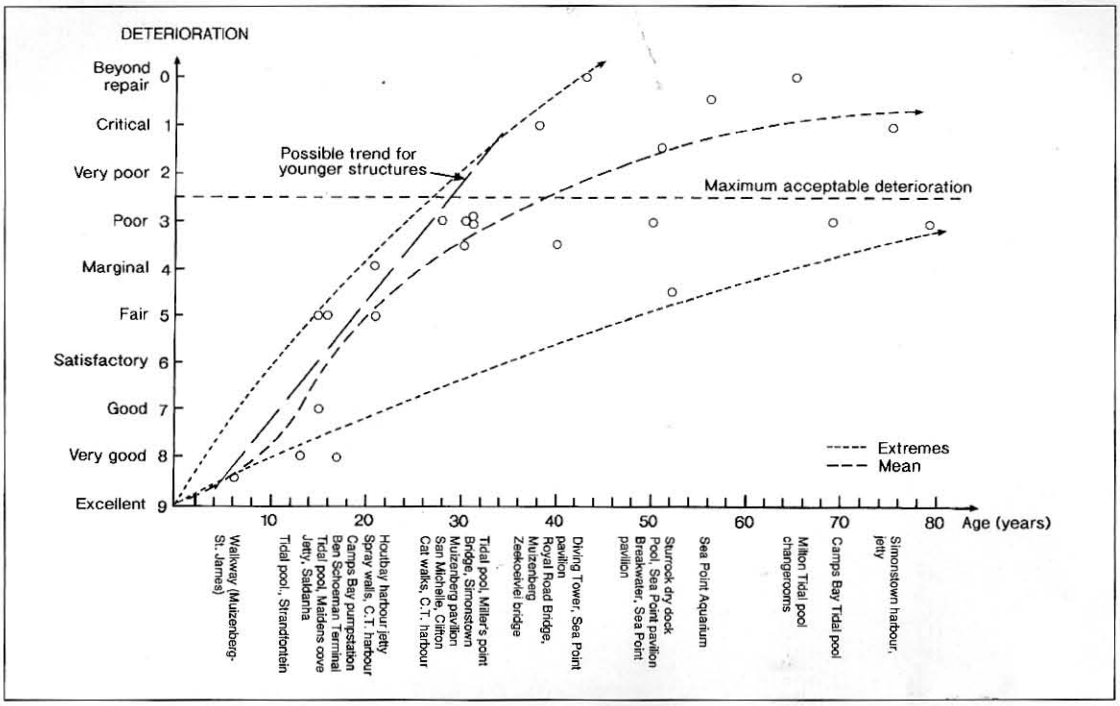

Figure 4: Severe coastal exposure deteriorataion curve

the mild coastal exposure curve it can be seen that no structures were found to be in a very poor or critical condition even though two structures were older than 90 years. It appears that younger structures in the mild environment will reach a stage of maximum acceptable deterioration after about 40 years.

When examining the curves, it is important to keep in mind that they merely indicate trends and are not adjusted for factors such as cover thickness and concrete strength. The curves are indicators of time spans to reach certain stages in the deterioration cycle and can be used tentatively in conjunction with repair cost data for future budgeting purposes.

3. MAINTENANCE AND REPAIR OPTIONS, AND REPAIR COSTS

After some time, most structures in a marine environment show signs of distress, whether cracking or spalling, due to environmental effects. Reinforced concrete, like other construction materials, may not be maintenance free and the future will require the development of realistically costed maintenance policies allied to appropriate repair strategies. On the other hand, "Design for Durability" needs to be more closely investigated by engineers with a view to this being possibly the most economical option on a life-cycle costing basis.

3.1 Maintenance and repair policies

Maintenance policies applied to existing reinforced concrete elements or structures generally involve the decision to implement one of the following repair philosophies.[4]

(1) **Leave alone** and accept the existing state of deterioration, monitor the deterioration with time and provide structural propping as required. (This is the way it is mostly done at present.) This implies doing nothing other than incorporating measures to protect public safety and accepting a significant reduction in structural strength or structural serviceability. Figure 5 shows a schematic representation for this option. There are many Peninsula structures where this state of affairs exists.

(2) **Apply barrier coatings** to inhibit further ingress of aggressive agents and to attempt to prevent corrosion.

(3) **Break out damaged areas** to the reinforcing steel or beyond, treat the steel, restore with a high quality patch material and apply a barrier coating to the damaged and surrounding areas. These are essentially holding repairs to slow down the corrosion rate, accepting the need for further repairs at intervals in order to reach the original intended life of the structure. See Figure 6.

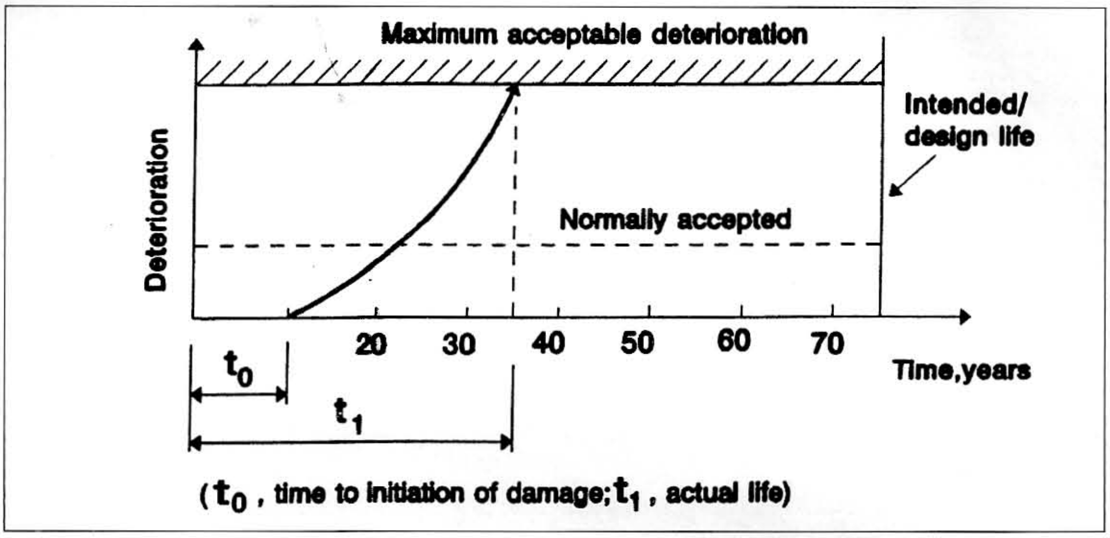

Figure 5: "Do nothing" repair philosophy [5]

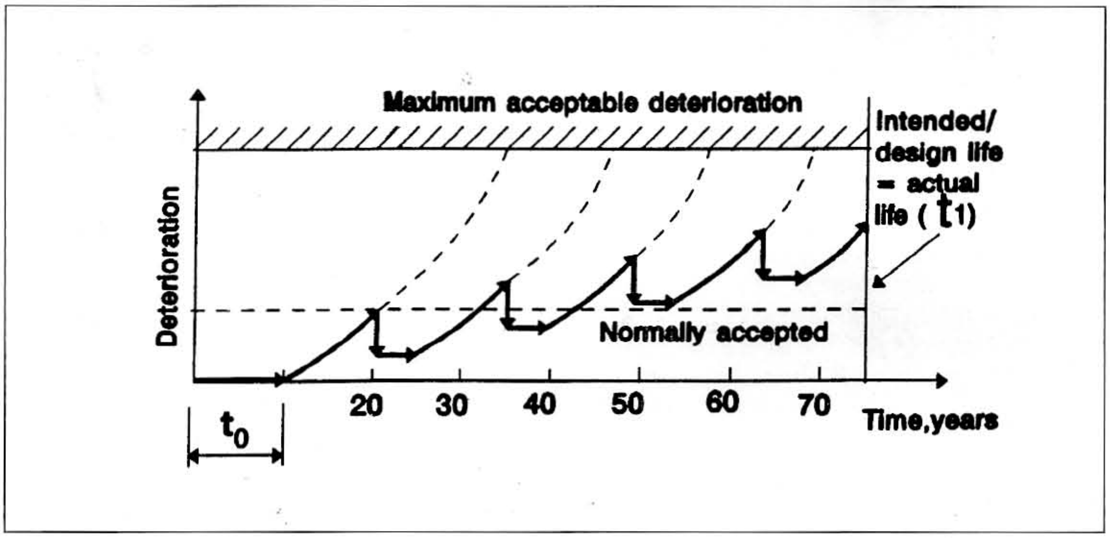

Figure 6: Regular holding repairs [5]

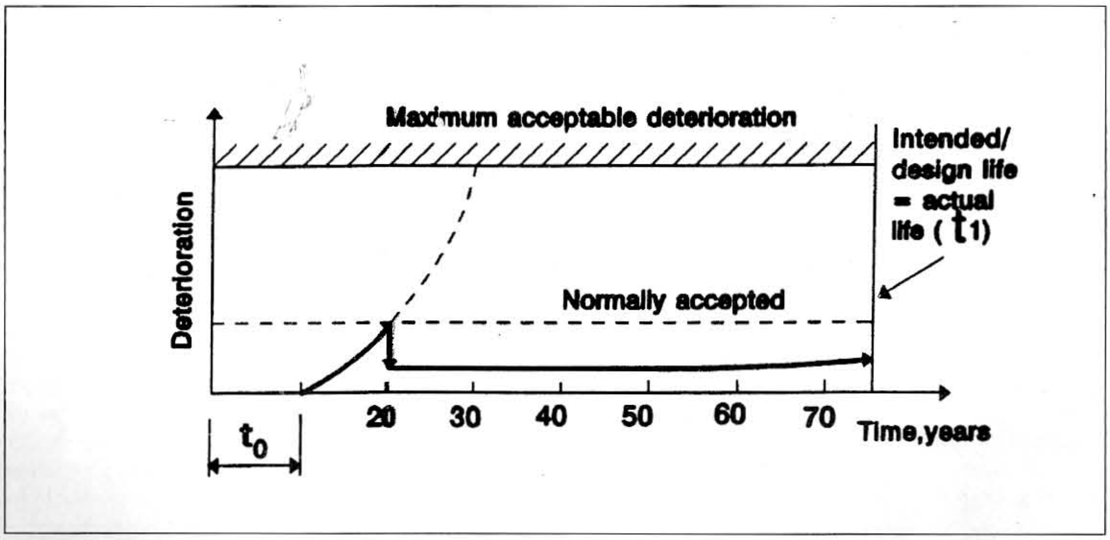

Figure 7: Cathodic protection of member

(4) **Cathodically protect** the reinforcement from corrosion. This will enable the structure to survive for its intended life and even beyond. Figure 7 illustrates schematically the application of cathodic protection and repairs at an arbitrary age of 20 years.

(5) **Chloride removal and/or re-alkalisation** of the concrete. This method of repair removes chlorides that have penetrated the concrete and restores the pH of the concrete to a level which renders the reinforcing steel passive again i.e. with the necessary surface protection no further corrosion should take place. However, the technology is still largely in its developmental stages.

(6) **Cut out the member** and replace completely.

Further options include demolition and/or the complete replacement of the structure. The choice will be closely allied to the funds available for maintenance and how these are distributed over time.

Whatever the decision, the strategy must be based on a thorough structural investigation, the prime aim of which must be to discover the cause of the distress or deterioration.

3.2 Costing of repairs

This section deals with repair costs, based on the deterioration classification given in **Table 1.** These costs can be used for budgeting purposes, or to assess maintenance options.

The formula used for repair costing was:-

Cost = [Material Cost + Labour Rate + Access Factor] (1)

where:

Material cost – Actual costs (1994) calculated from quoted costs by manufacturers of repair materials (applied at recommended coverage rates and number of coats specified in product infomation manuals).

Labour rate – Actual costs (1994) quoted by contractors tendering for reinforced concrete repair work (includes all labour costs, wastage, profit and costs of consumables e.g. paint brushes, trowels, rollers, solvents, gloves, etc.)

Access factor – Cost of access to areas on structures to be repaired. This will vary to a large extent depending on the size of the structure and the location of areas to be repaired e.g. scaffolding for a 10 storey building will increase the cost of repair work by a large margin compared to repair work at ground level.

When estimating costs to repair reinforced concrete, the access factor will always have a major influence on the total cost. When repairs are initiated on a structure where scaffolding has to be used to access the areas that are deteriorating it is wise to do the best possible repair job using materials of superior quality to ensure a long life from the repairs. When repairs are carried out at ground level, it is easy to come back from time to time for further repairs. The importance of thorough supervision on site whilst repair work is being carried out to ensure good workmanship, especially in areas that cannot easily be accessed at a later stage, must be emphasised.

Another factor that has to be individually assessed for every repair job is the actual total area affected or deteriorated. This is different for every structure and can normally only be measured once removal of defective concrete has commenced due to the fact that some deterioration may not be identified during a visual assessment of the structure.

For the costing exercise in this study, areal extents of deterioration (and hence of necessary repair) expressed in percentage terms were arrived at by a visual assessment of structures. These percentages varied greatly, e.g. from 50% – 90% for category 3, and from 2% to 20% for category 6. In the costing exercise of repair of 1 m^2 of reinforced concrete, averages of these percentages were used. This means that the unit costs arrived at to repair will be the same for another structure only if the extent of deterioration is the same.

To estimate the length of cracks to be injected with a crack injection resin in category 6 also proved to be difficult because each square metre on a structure is different from the next. For purposes of this costing exercise it was taken to be an average of 1 m/m^2.

An example is given below which illustrates how the formula given above should be used – see Example 1. The example shows the total cost/m^2 to repair reinforced concrete in category 4 (excluding access costs). Other categories can be treated similarly, although the individual items of work required will obviously vary.

Table 2 contains a summary of costs for repairs in each category, assuming repair materials are supplied by four different manufacturers, calculated in the same way as in Example 1. The work done to category 9 and 8 should not be categorised as "repair work" but rather as "protection". The third column lists the percentage of 1 m^2 that is assumed damaged and is to be repaired. It is important to keep in mind that these percentages vary to a great extent and will be different for every structure.

It should be noted that the durability of patch repairs is not always assured, and has not been convincingly proved by long-term observation. This is particularly true if incipient anodes are created at the extremities of the repaired zone, by not adequately removing chloride-contaminated concrete.

Example 1 - Repair of 1 m^2 of reinforced concrete in deterioration category 4 with manufacturer A's products [Percentage spalling/m^2 equals 35%]

(1)	Removal of defective reinforced concrete to 20 mm behind the reinforcing bar	R 5.36
(2)	High pressure water-sand jet cleaning of the surface to remove all paint, organic matter, loose concrete and dust	R 13.73
(3)	High pressure grit blasting to remove all iron oxide (rust products) from reinforcing steel	R 3.11
(4)	Apply anti-corrosive coating on the steel rebar	R 12.60
(5)	Apply a bonding agent on spalled areas to ensure strong bond between old concrete and repair mortar (35% of area)	R 1.66
(6)	Patching of spalled and raked out areas with repair mortar (35% of area)	R114.52
(7)	Application of a surface coat to fill blowholes and cracks to provide a smooth surface for a protective surface coating	R 18.04
(8)	Application of a protective surface coating	R 30.78
	TOTAL	**R 199.80/m^2**

Table 2 - Summary of costs to repair 1 m^2 of reinforced concrete (1994 costs)

Category	Description	% to repair	Manufacturer A	Manufacturer B	Manufacturer C	Manufacturer D	Mean
9	Excellent	0	R 24.03	R 20.58	R 63.05	R 27.62	R 33.82
8	Very Good	0	R 72.27	R 67.09	R 105.59	R 71.26	R 79.05
7	Good	10	R 86.56	R 69.13	R 110.59	R 74.70	R 85.25
6	Satisfactory	15	R 140.04	R 132.96	R 176.17	R 140.04	R 147.30
5	Fair	25	R 163.36	R 134.06	R 175.83	R 178.20	R 162.86
4	Marginal	35	R 199.80	R 160.84	R 203.92	R 221.62	R 196.55
3	Poor	45	R 236.24	R 187.63	R 232.01	R 265.04	R 230.23
2	Very Poor	60	R 499.19	R 400.77	R 496.44	R 330.17	R 431.64

3.3 Costing of cathodic protection

In the calculation of the cost to install cathodic protection on 1 m^2 of concrete the most important factors that have to be taken into account, according to Stevenson[6] are:

- The amount of reinforcing steel in the concrete element;
- The continuity of the reinforcing steel;
- The amount of spalling to be patched.

Usually, the extent of repair works is the overriding factor influencing costs. The patching process can be very costly where the soffits of slabs or beams have to be patched. Costs also increase where the cover to the reinforcing is small, since the cover will have to be increased for the anode to be a sufficient distance away from the cathode. Where cathodic protection is applied to the upper surface of a bridge, costs are less because of easier access and work on a flat surface.

***Costs* (1994)**

(1) **Titanium mesh (anode)** - R160.00/ m^2
(2) **Cathodic protection hardware & design** - R50 to R70/m^2
(3) **Repair works (patching, formwork, guniting)** - R100 to R350/m^2
(4) **Power consumption** - 40 to 100 watts/1000 m^2 (i.e. 1 lightbulb/1000 m^2 thus cost/ m^2 is negligible.

Total cost/m^2: R300 to R600/m^2

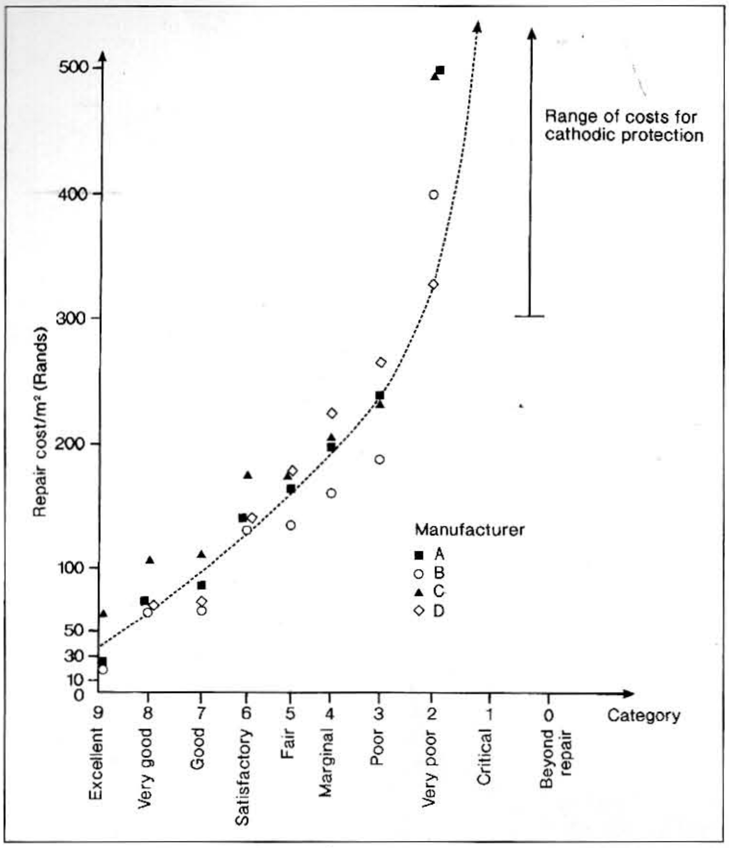

Figure 8: Repair costs for reinforced concrete structures (1994 costs)

Figure 8 is a graphic representation of repair costs. The horizontal axis has been adjusted approximately to account for the time it takes to move from one deterioration category to the next, using data from figures 3 and 4 . This figure clearly illustrates how costs increase as the amount of deterioration increases with time.

When a structure is in an excellent condition, it is fairly cheap to "protect" the structure from ingress of chlorides (and CO_2). Repair costs begin accelerating thereafter as deterioration increases. It can also be seen how costs suddenly rise when repairing category 6 due to the high labour cost of crack injection. Once categories 3 and 2 are reached, consideration should be given to permanent repair by installing cathodic protection. However, in order to assess which option would be the cheapest in the long-run, total costs over the life of a structure have to be compared. This is dealt with in Part 2 of this paper.

Following is a consideration of short-term maintenance and repair, and the question of future maintenance and repair budgeting

3.4 Minimising costs of short-term maintenance and repairs

Once a structure has been assessed and placed into one of the deterioration categories of Table 1, an estimate of short-term repair costs can be obtained from Figure 8 (not allowing for access costs). Clearly, once it is decided that repairs should be carried out, this should be done preferably as rapidly as possible for two reasons:-

(1) The longer a reinforced concrete structure is left to deteriorate, the deeper the chlorides (or the carbonation front) will penetrate the structure. It is important to keep in mind that in severe coastal exposure climates the rate of chloride diffusion may be high i.e. chlorides begin to penetrate the surface layer immediately after construction and may reach a corrosion threshold level at the steel after 10 – 15 years, and even earlier in some cases. This depends very much on the adequacy of design and construction.

(2) The second reason is illustrated in **Figure 8** which shows that costs for repair increase rapidly as deterioration increases. Therefore, it will always be cheaper in the short-term to initiate repair work at the earliest possible stage in the deterioration cycle.

Some repair materials are only suited for certain applications e.g. silane/siloxanes are effective only if the chlorides are still fairly remote from the steel due to the fact that they line pores in the concrete rather than block them. Silane/siloxanes do not prevent carbonation.

The method of repair will also depend on the state of a structure i.e. a structure can exhibit a great amount of cracking due, for example, to excessive shrinkage cracking at original construction, but minimal chlorides could have penetrated if it is situated in a wind and rain protected area. This means that raking out might not have to take place, merely crack injection and coating. Cracking could also be minimal on the other hand, but chloride diffusion very deep, to a point past the steel and having reached a concentration at the steel which is at or above the corrosion threshold level. This means that breaking out of the chloride contaminated concrete will have to take place, as well as grit blasting of the corroded steel, followed by patching. In the case where chlorides have only penetrated to a depth of 50% – 70% of the covercrete it is important to keep in mind that if the chloride concentration is very high at the surface, sealing the surface will not necessarily be the correct approach because the concentration gradient will cause chlorides to continue to diffuse to the steel. The correct repair method would then be breaking out and patch repairing.

From the above it is clear how crucial it is to establish the depth of chloride ion diffusion and/or carbonation. Diagnosing a structure according to a visual assessment is not sufficient. It is also important to consider the environment before any repair work is carried out to counteract the deteriorating factors that are causing the particular structure in question to deteriorate.

By considering the factors listed in the preceding sections when formulating maintenance and repair strategies, a cost effective short-term solution can be pursued (cathodic protection is a long-term repair solution). However, in order to plan for future maintenance expenditure, formulas are necessary (a) to calculate repair costs at some predefined point in the future, and (b) to enable budgeting for those future expenses.

4. FINANCIAL CALCULATIONS FOR FUTURE MAINTENANCE AND REPAIR BUDGETING

Most concrete structures are repaired or maintained only when some form of deterioration is noticed. This trend is however changing in that maintenance managers now have to make budgetary forecasts of maintenance expenditure envisaged for the future year(s)[7]. This section links the cost and deterioration rate information discussed in the previous sections with formulas which can be used to establish future repair costs, and gives aid in budgeting for periodic maintenance expenditure.

4.1 Future value of repair costs

The calculation of an estimated future value of the repair cost/m^2 of reinforced concrete involves the projection of the present cost. The compound interest equation that is used to compute the future value equivalent of the present price is[8]:

$$S = P[1 + b]^n \tag{2}$$

where:

- **S** is the projected estimated price (future value) for maintenance and repair/m^2 of reinforced concrete
- **P** is the present day price for maintenance and repair/ m^2 of reinforced concrete
- **b** is the escalation index for building renovation (concrete work)
- **n** is the number of years from the present until maintenance is to be carried out.

Figures 3 & 4 in combination with **Figure 8** can be used to establish values for **'P'** and **'n'**. From **Figure 3**, for example, it takes a structure in a mild coastal exposure climate about 24 years to reach a 'Satisfactory' condition after initial construction. The present cost to repair a particular structure which has reached this state of deterioration is an average of R147,48/m^2. This value is then entered into equation (2) to calculate a future value equivalent (where **'b'** = 13.6% (average from **Ref. (9)**) i.e.

$$S = R\ 147.48\ [1 + 0.136]^{24}$$
$$S = \underline{\underline{R3146.39/m^2}}$$

4.2 Budgeting - Calculation of monthly deposit amounts to pay for future maintenance

A series of equations is used to calculate the amounts required to be deposited in an interest-bearing account in order to accumulate sufficient funds to carry out maintenance at some specified date in the future. For purposes of this paper this amount has been assigned the abbreviation **'D'**.

In order to calculate the values of **'D'** for each year a series of stages should be followed, starting with the calculation of an estimated future value of the repaid cost/m^2 of reinforced concrete, i.e. **'S'** (same as above).

The next stage involves the calculation of the relationship between the effective interest rate and the rate of increase or decrease of the renovation indices for concrete work. For this calculation the present worth formula is used to find the relationship between the two.

The formula used is[8]:

$$w = \frac{[1 + g]}{[1 + i]} - 1 \tag{3}$$

where:

- **w** is the present worth
- **g** is the rate of increase or decrease of renovation indices
- **i** is the interest rate of deposit account.

The next formula is used to calculate the first payment of a geometric gradient series. A geometric gradient payment series is a series of cash flow sequences that increase or decrease by a fixed percentage at each payment interval. This method of calculation is used because it enables the amount to be saved every year to be adjusted by the increase or decrease in renovation costs. This is performed so that the amount paid into the deposit account each year escalates according to renovation costs, and does not remain static[10].

The first payment is calculated and then used again to calculate the second annual amount necessary, and so on, to collect sufficient funds to pay for maintenance and repairs.

This formula is[8]:

$$R = S\ [1+g]\left[\frac{1}{1+w}\right]\left[\frac{w}{(1+w)^{n}-1}\right]\left[\frac{1}{(1+i)^{n}}\right] \quad \textbf{(4)}$$

where:

- **R** is the first annual payment of geometric gradient.
- **S** is the projected estimated price (future value) for maintenance and repair / m^2 of reinforced concrete.
- **g** is the rate of increase or decrease of renovation indices.
- **w** is the present worth.
- **n** is the number of years from the present until maintenance is to be carried out.
- **i** is the interest rate of deposit account.

Below is an example to illustrate how the initial value of **'D'** is calculated. The value of **'g'** i.e. the rate of increase of renovation indices is taken to be 10% and **'i'** i.e. the interest rate of a deposit account is taken to be 5%.

Budgeting example

Step 1:

$$W = \frac{[1+g]}{[1+i]} - 1\ ;\quad W = \frac{[1+0{,}10]}{[1+0{,}05]} - 1\ ;\quad W = 0{,}0476 \quad \textbf{(5)}$$

Step 2:

$$R = 3146{,}39\ [\ 1+0{,}10\ ]\ \left[\frac{1}{1+0{,}0476}\right]\left[\frac{0.0476}{(1+0{,}0476)^{24}-1}\right]\left[\frac{1}{(1+0{,}05)^{24}}\right]$$

$$R = 23{,}75$$

Thus, R23,75 represents the first payment amount **'D'** (which is to be increased by 10% per annum) in the annuity series to be invested in a deposit account earning 5% which will generate the required R3 146,39 at the end of 24 years.

Use of the above approach by maintenance managers of commercial and industrial structures for budgeting for future maintenance expenditure can give owners a good indication of the sums that should be accumulated annually for repair work to reinforced concrete in the future. This figure will never be precise because of the inaccuracies in forecasting the area that will have deteriorated on a particular structure after a given amount of time. It is also impossible to forecast a precise escalation index for the repair costs.

Public authorities usually work according to a different system of budgeting in which amounts for repairs to pre-selected structures are put aside from the budget on a yearly basis. Nevertheless, the information and methods given in the paper can assist such authorities in planning for maintenance and repair on a more rational basis, provided surveys of the present state of structures have been carried out.

The guidelines and information given in this paper can be used effectively if the most economical point in time at which to carry out maintenance and repairs is known. An estimate of this time requires an approach based on the life cycle costing (LCC) of structures, together with the use of suitable decision models. These aspects will be addressed in Part 2.

5. CONCLUSIONS

Broad observations and conclusions that can be drawn from the above are:-

(a) Using a suitable classification system for deterioration of reinforced concrete structures, it has been possible to assess numerous structures in the Cape Peninsula area. Dividing the structures into two groups based on either "Mild" or "Severe" coastal environment it was found that, at present, younger structures in a mild coastal environment begin cracking and spalling significantly at an age of 20 – 25 years, and those in a severe exposure climate at about 15 years.

(b) A series of maintenance and repair options has been considered, and a cost curve prepared indicating the cost per m^2 to repair reinforced concrete in various stages of deterioration. Costs begin to rise very steeply as deterioration increases, and it appears that cathodic protection becomes the more viable economic repair solution for structures in a relatively advanced state of deterioration. From a short-term maintenance perspective, it is always cheaper to repair a structure as early as possible in the deterioration cycle.

(c) A series of formulae are provided to assist maintenance managers to make budgetary forecasts of maintenance expenditure for future years. However, it is extremely difficult to forecast accurately the rates of deterioration of structures, and the economic factors that will affect repair costs.

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