A WEB BASED TOOL FOR SELECTING REPAIR OPTIONS AND LIFE CYCLE COSTING OF CORROSION DAMAGED REINFORCED CONCRETE STRUCTURES

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ABSTRACT

The UK concrete repair industry is believed to turn over $2 billion per annum, more than 3% of the entire UK construction industry turnover. While many structures are well maintained within a suitable management program, a number of owners do not have the resources to cope effectively when presented with a one off problem, their first or their only case of reinforcement corrosion.

This paper described a new web based tool to guide the user through the process of:

a. prediction of time to chloride or carbonation induced reinforcement corrosion,
b. the selection of effective repair options,
c. the budget costing of repair options
d. life cycle costing of the chosen repair options

Examples of its application are given for both carbonation and chloride induced corrosion. Elements of the tool can be used independently or sequentially, depending upon the requirements and expertise of the user and on the available information from the structure under evaluation. Costs for different techniques have been developed by a peer group of UK contractors, consultants and materials suppliers. Although given in British Pounds they can be used by simple exchange rate conversion in other countries if no better local data are available. Costs should be considered comparative budget prices rather than absolute values.

Case studies are given where the paper has been applied to reinforced concrete structures suffering from chloride and from carbonation induced corrosion. The studies show that by quantitative analysis of good quality survey data the costs and advantages of different repair options can be analysed objectively.

INTRODUCTION

The UK concrete repair industry is believed to have a turnover of $2 billion per annum, more than 3% of the entire UK construction industry turnover. While many structures are well maintained within a suitable management program, a number of owners do not have the resources to cope effectively when presented with a one off problem, or their first case of reinforcement corrosion.

Under a "Partners in Industry" (PII) project, sponsored by the UK Department of Trade and Industry, a website was developed to guide those managing a structure through some of the major processes of choosing a technically valid and cost effective repair for a reinforced concrete structure suffering from reinforcement corrosion. The tool can be found at http://projects.bre.co.uk/rebarcorrosioncost/ [1].

The web based tool consists of a series of independent steps to determine

1. the cause of corrosion,
2. the time to corrosion initiation,
3. repair options
4. repair costs
5. life cycle cost of the repair

Each step is an independent module and can be run at any time and in any order providing that the necessary inputs are available.

STEP 1: TIME TO CORROSION

This has an introductory page that presents information on the definition of Time to Corrosion Initiation and how it can be assessed using an external tool (DME 5.1) developed with Microsoft Excel. The tool can be downloaded and used to estimate time to corrosion initiation due to chlorides or carbonation. The tool requires reinforcement depth measurements and either associated carbonation depths or chloride profiles.

Chloride profiles are used to predict the time to initiation by using a parabolic approximation to the error function solution to Fick's second law of diffusion [2].

Alternatively, if carbonation is the suspected cause of corrosion, then carbonation depths and corresponding reinforcement cover depths are fed into a statistical tool that uses a power law approximation to estimate time to corrosion.

where: x = carbonation depth at
t = time
n is an exponent usually 0.5

The time to corrosion is required in the next step of selecting a repair strategy. It may be predicted from the models, estimated from experience or known to have passed from observation (it may have passed on some elements of a structure but not on others, giving opportunities for different approaches in different locations).

STEP 2: REPAIR STRATEGY SELECTION:

This step presents a tool and some technical information on how to select the most appropriate repair technique based on the results of step 1. The tool takes as its inputs the source of corrosion (i.e. carbonation or chloride), the time to corrosion initiation and year of end of service life. Based on these inputs, the tool provides a recommendation on the appropriate repair strategies.

For example, if a structure (or element) has not yet started to corrode and is not estimated to do so for several years, a preventative strategy may be suitable. This might consist of applying a suitable coating to keep out chlorides or to significantly slow down carbonation. However, if corrosion is already underway then impressed current cathodic protection or electrochemical chloride extraction are options for chloride induced corrosion. Further information is provided to help the user to select one or more options for further consideration.

A typical repair option screen is show in figure 1 for the case of a University building suffering from reinforcement corrosion. Analysis of a detailed survey which included carbonation depths, cover depths and chloride contents showed that carbonation induced corrosion had damaged areas suffering from low cover and poor quality concrete (e.g. honeycombing). However, the distribution of carbonation depths measured and the distribution of cover depths shows a low risk of corrosion for a significant time as shown in figure 2.

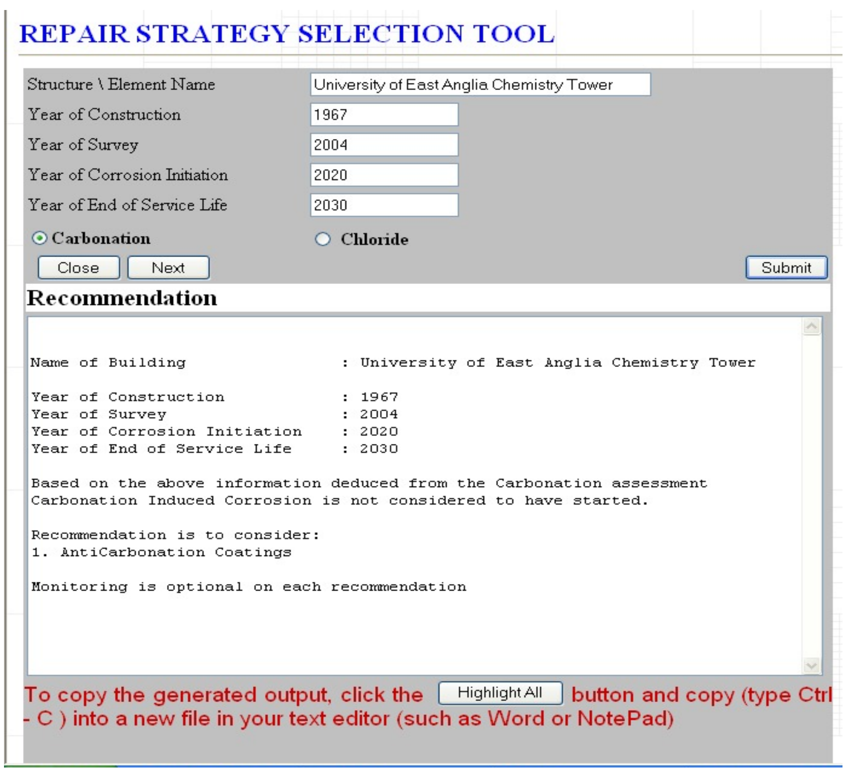

Figure 1 – Recommendation of a repair Strategy of a Building Tower Based on the Time to Corrosion.

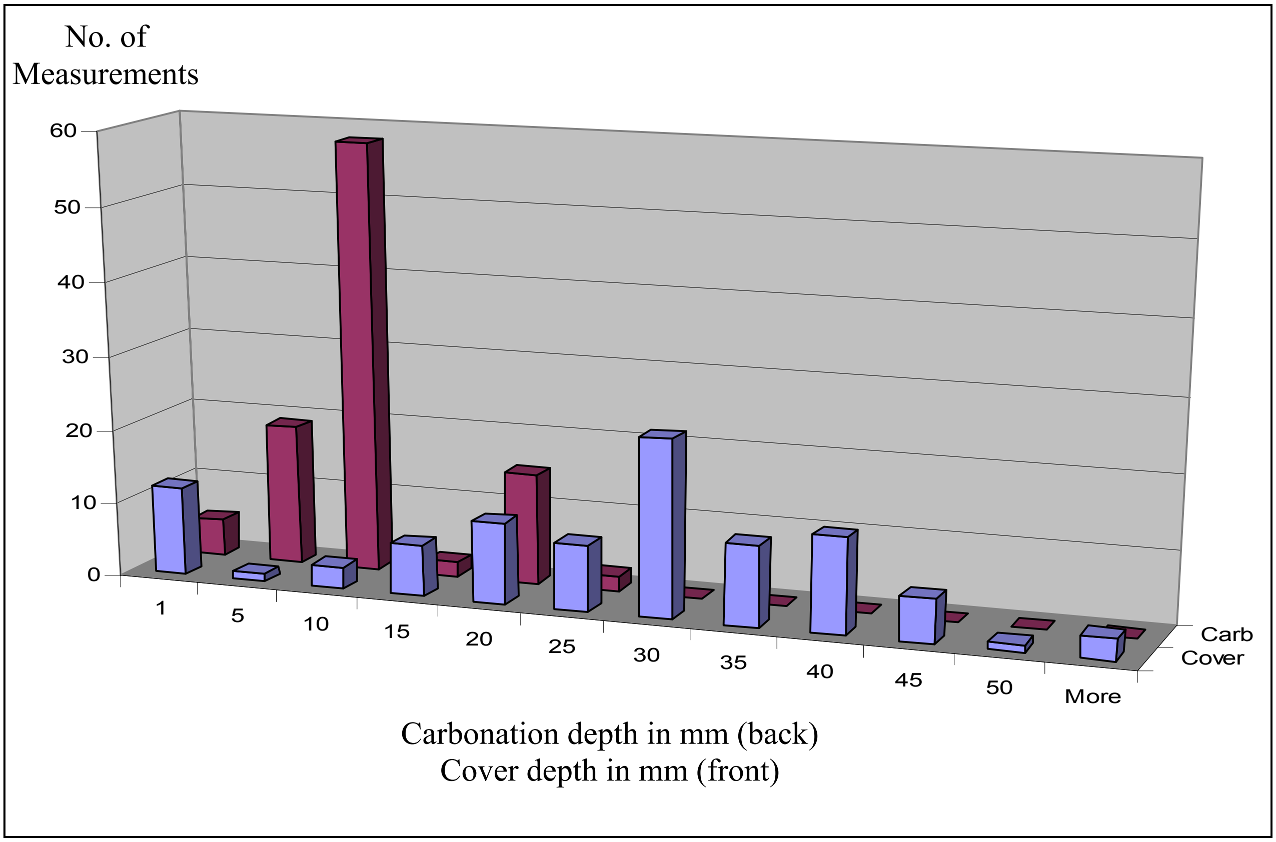

Figure 2 – Statistical Analysis of Carbonation and Cover data (depth in mm vs. number of readings) showing that generally cover is far greater than carbonation depth

A simple power law equation can be used to model the rate of progress of the carbonation front [3]

$$x = kt^{1/2}$$

where x is the carbonation depth, t is time and k is a constant. The value of k was determined for each of the 100 measurements shown in Figure 2. The k value was then used to predict the time (or year) for the carbonation front to reach the reinforcement for each measurement location, i.e. the time to initiation of corrosion by calculating t when x is the cover depth. The values are shown in Figure 3.

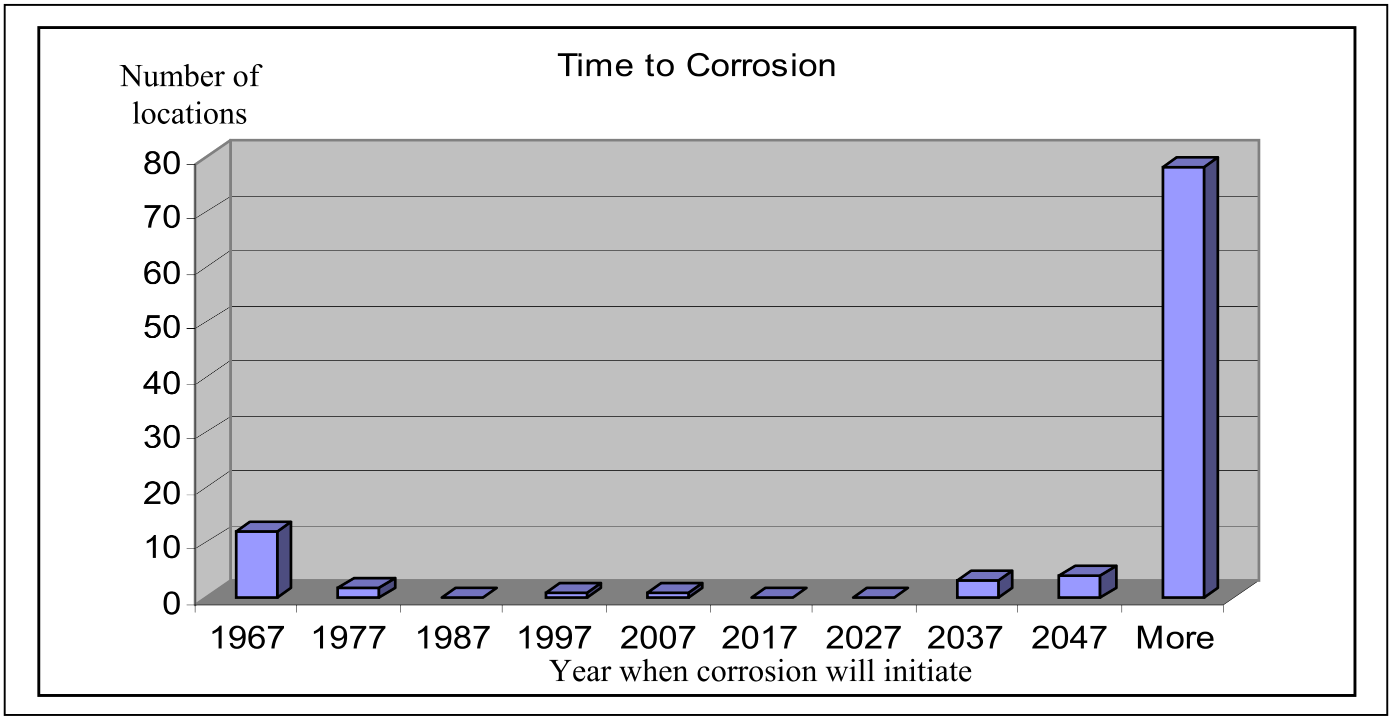

Figure 3 – Statistical Analysis of time to corrosion showing that areas of low cover and poor concrete quality (high carbonation rate) are already corroding. If these areas are repaired, negligible further corrosion is expected until 2037 or later.

Thus it can be seen that there are defects that lead to early corrosion that has already occurred. However, no significant corrosion initiation events are expected from now until 2037. This is well beyond the client's required life extension of 25 years (from repair in 2005 to 2030). An anticarbonation coating applied after repairing existing corrosion damage would minimise the risk of future damage.

On being presented with a list of repair options, one can be selected and then checked for its suitability. Figure 4 is a page where checking the boxes will show whether or not galvanic or impressed current cathodic protection is likely to be suitable. Options are not excluded but responses advise that life cycle costing may exclude an option e.g. when selecting impressed current cathodic protection where there is a short remaining life, or where great care must be taken e.g. where applying impressed current cathodic protection to structures containing prestressing strands.

In the example shown, lack of electrical continuity of the reinforcing steel and lack of a power supply make impressed current cathodic protection difficult and expensive. The high resistance concrete means that a galvanic anodes trial would be required to determine if they could adequately protect the steel and what spacing would be required between anodes. Therefore neither approach may be the most appropriate as stated in the tool's response.

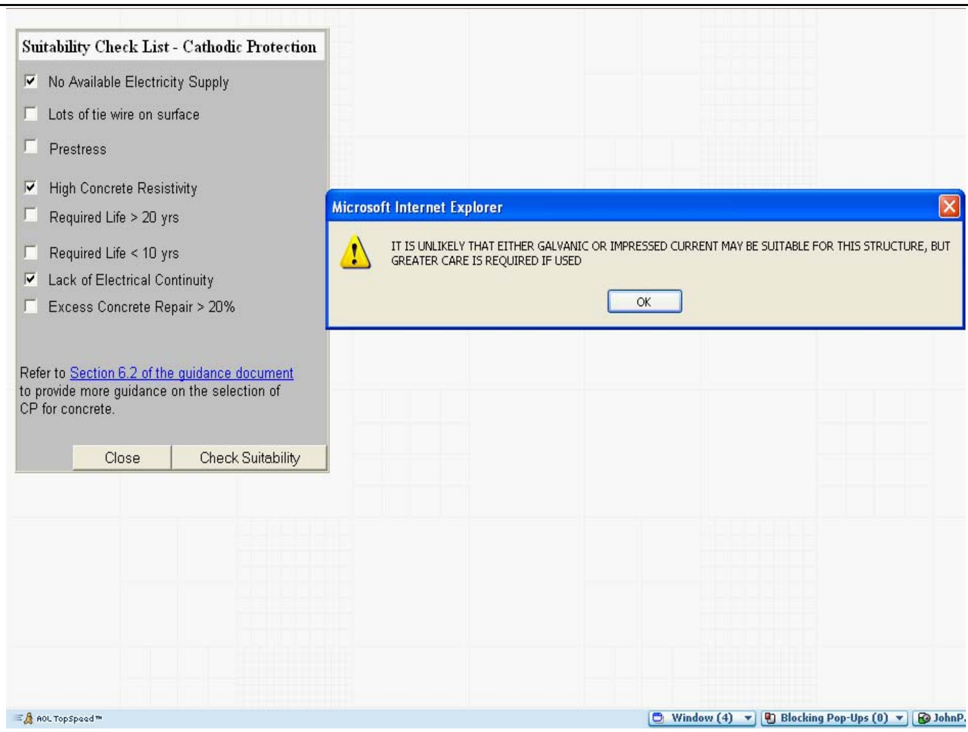

Figure 4 – Suitability check list for cathodic protection

STEP 3: REPAIR TECHNIQUES COSTING:

This chapter gives a brief description on all the techniques presented within the system. Each technique is represented as a sub-section to this chapter. Each sub-section presents in detail a description of the technique and also a tool to calculate the cost of applying the technique. This is done by reference to a table of fixed costs and costs per square meter.

Costs were derived from a range of sources. Costs for impressed current cathodic protection were derived from a UK Highways Agency Bridge Advice Note [3], written by Contractors, Consultants and materials suppliers who are members of the UK Corrosion Prevention Association. Other data were collected by a peer group of contractors, consultants and materials suppliers who partnered the project with contributions in kind.

Figure 5 shows the build up of a budget cost for galvanic cathodic protection

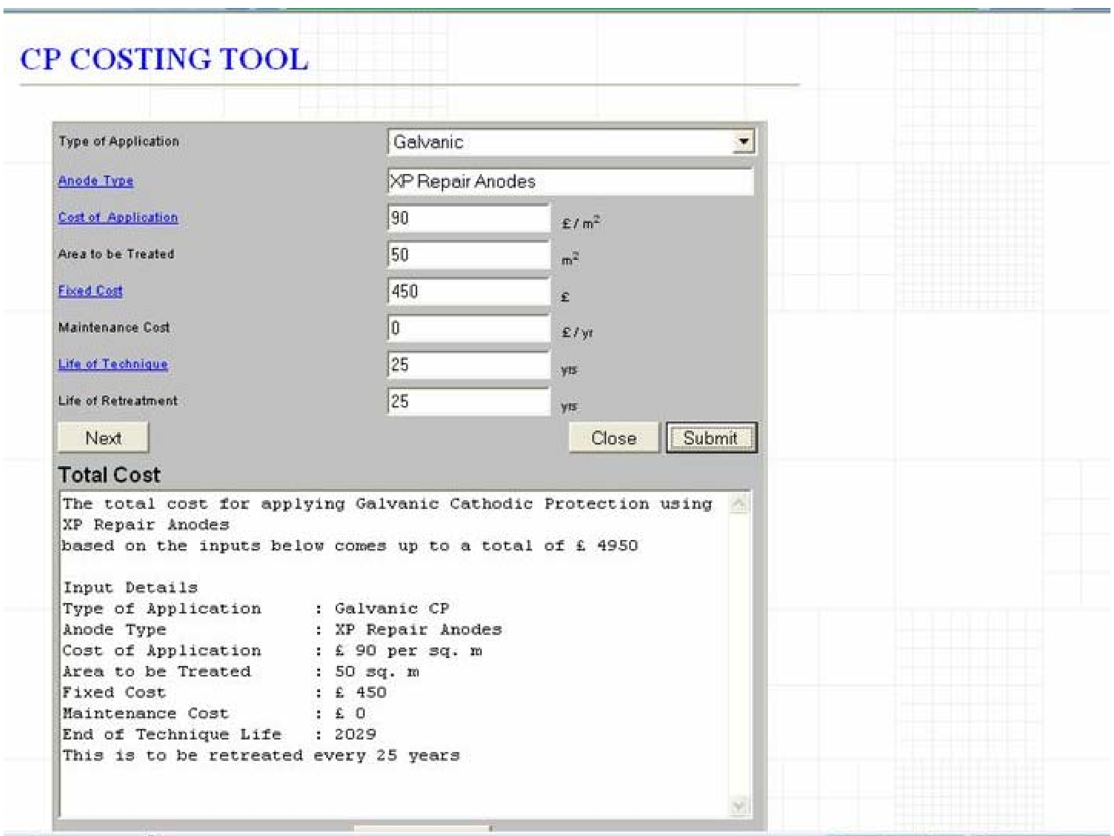

Figure 5 – Cost estimate for applying galvanic anodes in repairs for a walkway with leaking joints.

The costs for galvanic anodes, patch repairs, replacing the leaking waterproofing and applying a silane coating was compared with applying impressed current cathodic protection. The results are shown in Table 1.

Table 1 – Comparative costings for conventional repair and Impressed Current Cathodic Protection

Library Walkway	No	Units	Cost/ unit	Fixed Cost	Repair Cost
Patch Repairs	50	Defects	£ 100.00	£ 500.00	£ 5,500.00
Galvanic Anodes	150	Anodes	£ 30.00	£ 450.00	£ 4,950.00
Replace Waterproofing etc.	425	m^2	£ 200.00	£ 8,500.00	£ 93,500.00
Silane Coating	1000	m^2	£ 10.00	£ 1,000.00	£ 11,000.00
ICCP	1000	m^2	£ 200.00	£ 28,000.00	£ 228,000.00
TOTAL wth CP (reduced repair cost, no galvanic anodes)					**£ 336,625.00**
TOTAL without ICCP					**£ 108,625.00**

NOTE – The ICCP option reduces repair costs by 25% as less extensive cutting out is required. The galvanic anodes are also excluded. If full ICCP is included then the silane would not be needed.

STEP 4: COMPARATIVE WHOLE LIFE COSTING

This module of the website provides a tool to calculate the whole life cycle cost of the project for a given number of years. It presents a description on how to use the tool and the economic aspect of the output produced from the analysis.

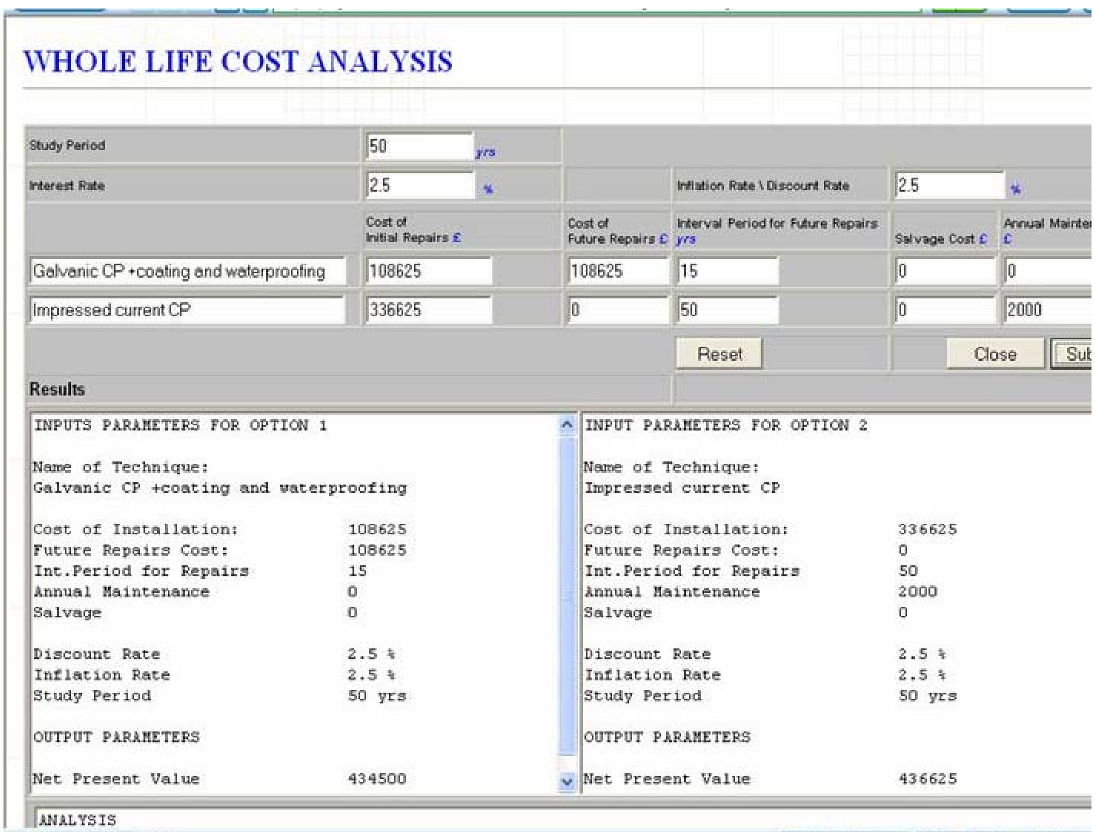

Figure 5 – Life Cycle costing Page comparing Conventional Repair with Galvanic Anodes with Impressed Current Cathodic Protection

A whole life cycle cost analysis was carried out using the examples in Table 1 for a 50 year life, assuming a 15 year life for the patch repair, galvanic anodes coating and waterproofing approach and a 50 year life for impressed current cathodic protection. Using the same discount and interest rate of 2.5% over a period of 50 years galvanic anodes are marginally cheaper. The change to ICCP being most cost effective is at 60 years. However, using more realistic values with a higher interest rate the galvanic anodes have a lower Net Present Value and Equivalent Uniform Annual cost over all realistic protections.

The client's requirement is for a 25 year life extension with maintenance. Also, the combination of excluding chlorides and the localised nature of the problem around failed joints means that the galvanic option is likely to achieve more than a 15 year life, probably around 25 years. This, coupled with the fact that the client only required a 25 year life means that the financial argument is strongly in favour of the galvanic anode approach on both a first cost and hole life cost basis.

The first costs and the life cycle costs should be taken as comparative values between options. They should not be used for drawing up budgets for repair without consulting an experienced contractor for his estimate after looking at the job.

CONCLUSIONS

2. A web based tool has been developed for corrosion of steel in reinforced concrete structures to guide the user through the processes of:
    a. prediction of time to corrosion,
    b. the selection of effective repair options,
    c. the costing of repair options
    d. life cycle costing of the chosen repair options

3. Examples of its application are given for both carbonation and chloride induced corrosion.

4. The case studies show that by quantitative analysis of good quality survey data the costs and advantages of different repair options can be analysed objectively, offering the owner choices with advantages and limitations in terms of first cost, life cycle costs, maintenance costs and time to repairs.

5. Elements of the tool can be used independently or sequentially, depending upon the requirements and expertise of the user and on the available information from the structure under evaluation.

6. Costs for different techniques have been developed by a peer group of UK contractors, consultants and materials suppliers. Although given in British Pounds they can be used by simple exchange rate conversion in other countries if no better local data are available. Costs should be considered comparative budget prices rather than absolute values.

ACKNOWLEDGEMENTS

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He would also like to thank the Department of Trade and Industry who funded the development of the web tool, and the collaborators on the project, He would particularly like to acknowledge Kofi Abora of BRE who did the programming. A full list of collaborators is to be found at the website.

REFERENCES

[1] Effective Cost Analysis for Repairing of Corrosion Damaged Reinforced Concrete Structures – Guidance Document and Model http://projects.bre.co.uk/rebarcorrosioncost/

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[3] Design Manual for Roads and Bridges Vol. 3, Section 3, Pt. 3, "Cathodic Protection for use in reinforced concrete highway structures. BA/83/02. Publ. The Stationery Office, London. Downloadable from: **http://www.official-documents.co.uk/document/deps/ha/dmrb/vol3/sect3/ba8302.pdf**