A SYSTEMATIC METHOD FOR THE APPRAISAL AND RENOVATION OF EXISTING STRUCTURES

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A dissertation submitted to the Faculty of Engineering,
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in fulfilment of the requirements for the
Degree of Master of Science in Engineering.

Johannesburg, 1993

DECLARATION

I declare that this dissertation is my own, unaided work. It is being submitted for the Degree of Master of Science in Engineering in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

SIGNATURE OF CANDIDATE .... [signature] ....

.... 20 .... DAY OF .... December 1993

ABSTRACT

Although the history of building structures in Southern Africa extends back only about 200 years, many older important historic structures are now approaching an age at which serious deterioration has become evident and the necessity for repair and renovation is essential in order to preserve these structures.

The principal objective of this dissertation has been to formulate a systematic approach to the appraisal of old or historic structures taking into account the extensive knowledge base of research information available on age-related problems in structures.

As the appraisal and renovation procedure is very different from design of new structures, a systematic approach is required involving new investigative techniques and extensive experience not generally available. Consequently, an important aspect of this dissertation is the application of an Expert System to the appraisal of structures which includes guidance on the actual procedures, inspection methods and testing, diagnostic and forensic engineering and remedial technology.

The dissertation does not purport to be exhaustive in the technical sense, rather the intention is to demonstrate that a systematic, expert-system based approach to structural appraisal and renovation is feasible. However, all basic elements are in place for a comprehensive and technically complete treatment of the problem. Further research is required on establishing the full database and on diagnostic systems.

The information contained within the Expert System is unique to this subject and the logic systems and data systems required for the knowledge base are based on innovative research which has not been previously published.

Finally, the concepts and objectives of this dissertation have been applied to an actual case study which has validated the research undertaken in this dissertation.

ACKNOWLEDGMENTS

I would like to express my thanks to Professor Hans Scholz for his assistance and guidance throughout the investigation and research periods in the preparation of this dissertation which was greatly appreciated.

Also, I acknowledge the constant encouragement from my wife Ms Grethe Finkelstein and her financial support.

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SECTION 1.0 : INTRODUCTION

1.1 Objectives of this Dissertation

The appraisal procedure is complex and involves an extensive knowledge of the deterioration of structures. The personal experience of engineers in dealing with old structures often determines the extent of remedial work.

The objectives in a systematic approach to the preservation of historic structures centre around the assessment of the structural adequacy of the building and the need to ensure a future safe performance for the refurbished structure.

The principal objectives are summarised below:

1.1.1 The procedures should be undertaken systematically in a very different sequence from the design of new buildings and provide advice on all aspects of appraisal to inexperienced engineers including an assessment of the residual life of the structure.

1.1.2 It is important to establish a Knowledge Base on diagnostic techniques in the form of an Expert System program and the corresponding repair systems can then be determined based on the most likely causes of the observed problems.

1.1.3 In order to preserve the heritage of old historic buildings the history, purpose and environment of the original construction should be studied. This information also needs to be formally recorded.

1.1.4 Other important objectives relate to the detailed technical aspects of preservation and can be summarised as follows:

- Provide a systematic approach to appraisals and inspections in the form of procedure diagrams.

- Establish a Knowledge Base on durability problems and repair utilising the latest technology.
- Utilise modern computer systems such as Expert Systems.
- Prepare information leading towards a Code of Practice for appraisal and renovation.

1.1.5 Finally, it is a most important objective that assessment methods are in a form which is reasonably straightforward to use despite the increasing complexity of the matters being undertaken. For most purposes, design and assessment analyses would be linked to varying partial safety factors and only under very special circumstances would methods of reliability analysis be used by the designer.

1.2 Literature Survey

In recent years much attention has been devoted to the subject of appraisal and renovation of structures in Europe and the United States. Several major books and publications have been produced recently although the major source of reference material on the subject of this dissertation has been obtained from articles in research journals and magazine publications.

This dissertation covers a very wide scope of structural engineering subjects and consequently all specific references to published literature have been reviewed and referenced separately at the end of each relevant section of this dissertation.

Three important general publications on the general subject of appraisal of existing structures have been published recently and are reviewed below:

Ref [1]. "Appraisal of Existing Structures" Published by the Institution of Structural Engineers in London.

This document sets out the basic principles of appraisal in general terms but does not deal with specific diagnostic procedures or remedial technology.

Ref [2] "Guideline for Structural Condition Assessment of Existing Buildings" Published by the American Society of Civil Engineers. ASCE Standards ANSI/ASCE 11-90.

This docuemnt is very general and largely descriptive of the processes of condition assessment. Useful information is contained on standardising inspection and report forms.

Ref [3] "Inspection and Maintenance of Reinforced and Prestressed Concrete Structures" Published for FIP by Thomas Telford

The subjects dealt with in this document refer to key aspects of inspection particularly of prestressed structures. Also, maintenance of structures is comprehensively covered.

1.3 Research Contribution

The subject of appraisal and preservation of the built enviornment has only recently become an important research topic in civil engineering as a result of concern about the environment and interest in our architectural heritage. Consequently, little research has been published and the main research contributions of this dissertation are summarised below.

1.3.1 Systematic Process of Appraisal

A new procedure has been developed in Section 3.0 of this dissertation which is specifically related to the appraisal of old or historic South African structures. This procedure is more suitable to give guidance to inexperienced engineers compared with American and European systems which are concerned with more elaborate and much older structures. In addition, extensive data is generally not readily available on old South African structures and consequently a new systematic investigative procedure has been developed.

1.3.2 Diagnostic Methods

New concepts have been introduced in Section 4.0 of this dissertation defining a forensic engineering approach and in distinguishing between primary causes of problems in old structures and the symptoms which are obtained from tests or observations.

1.3.3 Application of an Expert System

Expert Systems have been introduced for diagnostic systems in the medical field and the application developed in Section 7.0 is unique in civil engineering. Although based on a shell program EXSYS, the Knowledge Based rules and the logic system constitute original research.

1.4 Overview of Section Headings

As the subject content of this dissertation covers a very broad range of materials, civil and structural engineering topics, the sequence and organisation of the Sections have been set out in the following logical sequence in order that each Section can be read independently.

- Section 1.0 Introduction
- Section 2.0 Conservation of Old and Historic Structures
- Section 3.0 The Systematic Process of Appraisal
- Section 4.0 Factors Affecting the Serviceability of Structures
- Section 5.0 Comparative Structural Design and Analysis
- Section 6.0 Repair Technology
- Section 7.0 An Expert System for Structural Appraisal
- Section 8.0 Testing and Instrumentation
- Section 9.0 Conclusions

SECTION 2.0 : CONSERVATION OF OLD AND HISTORIC STRUCTURES

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2.1 Urban Conservation in Southern Africa

World-wide concern for the preservation of the built environment has become a major issue in most developed countries over the past fifteen years and although urban conservation in Southern Africa is comparatively recent, the rapid urban growth has stimulated an awareness of the historic importance of early buildings and structures built in Southern Africa.

The rapid urban growth has resulted in our cities undergoing major redevelopment continuously and the change in Johannesburg from mining town to major metropolis has often resulted in the loss of historic buildings.

Within the urban environment of a modern city many old buildings and structures of historical significance are in need of preservation or reconstruction for new planning functions. It is essential that the structural condition of these buildings is assessed and the limitations of the existing designs are defined in specific terms before any reconstruction work takes place. The basic principles and methods of appraising an existing structure are very different from the normal design and analysis of a new structure and the objective of this dissertation is to define these basic principles within a systematic method of approach for carrying out a comprehensive assessment of the condition of historic or old existing structures, and recommending remedial action.

Outstanding structures have been constructed in Southern Africa in the past centuries and the corresponding spectrum of materials and techniques used in their design and construction ranges from the forgotten and outmoded, to the well tried and tested. Because all structures age and deteriorate a considerable fund of expertise is required to maintain all component parts of these valuable national assets in a sound and safe condition.

Historic building structures differ widely in configuration, size, condition and usage. Their appraisal has to be methodical and deal scientifically with all the parameters constituting a complete engineering system. Appraisal needs to draw a clear distinction between previous existing situations when standards were very different from modern code requirements.

Conservation of historic buildings has only recently become an important aspect of the awareness of the built environment and the contribution that architects and civil engineers have made to our cities. Within the last one hundred years cities such as Johannesburg have grown into a major metropolis. Buildings and structures from these early years provide an important link with the past.

During the building boom of the late sixties and seventies many buildings which formed part of an architectural and historical heritage have disappeared and it is becoming increasingly difficult to select and justify the preservation of old structures.

Appraisal and renovation of historic structures is rapidly becoming an important discipline within the field of structural engineering and calls upon the experience and knowledge of a broad range of specialities including structural analysis, material technology, diagnosis of problems and repair technology.

Since the preservation of historic structure is a vast and complex subject, the scope of this dissertation has been limited to deal mainly with buildings and structures constructed in South Africa.

In view of the diversity of terminology applicable the definition of terms used in this dissertation have been based on standard international nomenclature as follows:

"Preservation"	:	change nothing, maintain the structure to retard further deterioration.
"Restoration"	:	remove non-original additions, put back sections that have fallen off, return to original colour scheme, but do not add any new replacement elements.
"Reconstruction"	:	bring back to a known earlier state by replacing missing elements with replica or similarly reconstructed sections utilising modern materials.

"Adaptation" : change non-significant parts to enable new use, whilst preserving significant features.

"Conservation" : includes all the above.

2.2 The Need for Conservation

There are numerous reasons why it is important to preserve the historic links with past structural engineering. Johannesburg has recently celebrated its 100th anniversary and has a reputation for demolishing all buildings or structures which stand in the way of new developments. Many of the older buildings have become symbols of a period in history or have gained popular appeal as landmarks. Conservation, renovation and associated environmental improvements are seen not as luxuries but as an essential component of local economic regeneration. In other words a good environment is a good investment. Statistics in Europe and America reveal that reconstruction is a major growth area. Careful improvement of the environment will include historic buildings within the urban area complementing new development and creating a sense of pride in the historic development of the city. As expressed by Buckminister Fuller, perhaps one of the most innovate environmental engineers of this century. "Hope in the future is rooted in the memory of the past, for without memory there is no history and no knowledge. No projection of the future can be formed without reference to the past. Past, present and future, memory and prophecy are woven together into one continuous whole. In a clear understanding of the past lies the hope of our future."

In summary, the following two factors define the need for conservation of historic structures:

2.2.1 Preservation of tangible historic links with the past which serve as a sense of identity within the context of a modern urban environment.

2.2.2 The economics of redevelopment often favour the refurbishment of an older existing building compared with demolition and new construction and help to create an urban conservation environment which is unique and people-friendly.

As is now well established, the condition of old structures tends to deteriorate with time and when renovation is being considered it is important to ensure that the safety of the structure is maintained and remedial work carried out for the changing circumstances. Maintenance of structures is not normally a major consideration and only when problems become visible a more detailed assessment is necessary particularly if the structure or building is historically important.

Conservation must aim to keep buildings structures of Historical, Architectural and Technological merit and can help to reduce the demand on material and labour resources.

2.3 Economic Aspects of Conservation

Economic factors play a major part in deciding whether to conserve an existing building structure. The choices relate to the extent of deterioration in the structure and the method of conservation compared with demolition or strengthening. An extensive appraisal of the existing structure is needed combined with a comprehensive knowledge of repair technology. An Expert System could be developed to evaluate the optimum solution taking into account all the variable factors by statistical and heuristic methods.

Many of the precincts within the CBD of Johannesburg have historic buildings which are worthy of conservation. The redevelopment and conservation of these historic precincts and buildings could have a major positive economic benefit to the city in the following respects:

- Refurbishment of historic buildings is often more economical than reconstruction and creates a focus for environmental improvement.
- With upgrading and environmental improvement the surrounding land values are substantially increased adding considerably to the Council's rates income in that area and the economic rental that can be achieved.
- However, the local authority and building owners need to provide sufficient incentives for the preservation and upgrading of old buildings which are not necessarily of historic value particularly where the costs of refurbishment exceed the economic value of the building.

Our environment and conservation have become important aspects of modern engineering. No matter what purpose a building has had in the past it can be economically recycled to serve a useful role in the new South Africa. It will at the same time provide links with the past illustrating irreplaceable craftsmanship and artefacts which are of value to everyone, now and in the future. History cannot be changed but historical buildings can be adapted.

2.4 Criteria in Evaluating Structures

In deciding which structures or buildings should be considered for refurbishment or conservation several critical factors will influence the decision.

2.4.1 Historic Importance. It is clearly important to preserve historic structures and buildings which are good examples of architectural and social systems of the past.

2.4.2 Economic Considerations. The costs of conservation can be extremely high and often exceed the costs of new construction. However, with sufficient incentives, an economic development can result particularly if the historic building or structure is part of a conservation development precinct.

2.4.3 Structural Condition. Since all structures deteriorate over a period of time the appraisal of the condition of the main structural elements and the residual strength will determine the extent to which remedial reconstruction is required.

In order to evaluate the relative significance of the above three critical factors it is proposed that a PRESERVATION RATING could be determined using an Expert System if complete date is available.

2.4.4 Determine Preservation Rating P defined as:

P = P1 + P2 + P3 - P4

where P1 = Historic Significance Factor

P2 = Architectural Factor

P3 = Structural Adequacy Factor

P4 = Economic Factor

Each of these factors are weighted in terms of validity and importance.

For each factor Pn = ([Pn] x [Sn]) /

where Pn is the condition

Sn is weighted importance

For P_1 the S_1 conditions are Year of Construction

Historic Significance

Public Accessibility

P_2 the S_2 conditions are Architect Style

External Elevations

Internal Design

Major Features

P_3 the S_3 conditions are Structural Elements

Stability

P_4 the S_4 conditions are Cost Factor for Strengthening

Cost Factor for Reconstruction

2.5 The History of Early Structures in South Africa

In South Africa we have a history going back a mere 335 years or so to the time when Jan van Riebeeck arrived in the Cape of Good Hope. Very few buildings in the Cape date back more than 300 years and the oldest buildings in the Transvaal are a very young 130 years. These buildings are the only real links with our past history and are a constant reminder of the origin of our present culture. The history of early buildings in South Africa and particularly in the Transvaal is inextricably linked to the pioneering spirit of the people.

The traditional methods of construction and styles of Architecture were European in character and the structures and materials used in construction were often imported.

The emergence of reinforced concrete in this country appeared in the late nineteenth century and with the growth of the Portland cement industry most early multi-storey buildings were constructed in reinforced concrete.

The importance of preserving these historic buildings and structures is now realised in preserving our heritage.

With specific reference to Johannesburg a list of historic buildings and structures has been compiled by the Johannesburg City Council.

The 1890's were years of great expansion in Johannesburg and Sir Thomas Cullinan built some of the town's finest multi-storey buildings with bricks from the brickyards in Fordsburg and Boksburg.

Structural steelwork, mostly imported from Europe, was used extensively for major railway buildings and bridges.

Before the Second World War most railway bridges in South Africa were constructed of steel. The longest steel span, a 70 m Parker truss over the Gamtoos River, and the highest, with rail level 76 m above the bed of the Van Stadens River George, are both on the narrow gauge line between Port Elizabeth and Avontuur.

During the past 25 years several impressive structures have been built in concrete. The longest and highest concrete bridges are respectively the arch bridge over the Orange River at Bethulie (for both road and rail traffic) and the concrete boxgirder viaduct for the double line near Charlestown, which has a rail level 79 m above the floor of the valley.

With specific reference to the early history of buildings in Johannesburg the importance of understanding the phenomenal growth is fundamental to any conservation planning or renovation of the older buildings. A brief history of Johannesburg is given in Ref. [4].

2.6 Official Control of Conservation and the Law

Various official bodies are either responsible for the preservation of historic buildings or have a direct environment policy protecting our heritage and environmental conservation. The major functions of the official bodies are briefly described below:

2.6.1 National Monuments Council (NMC)

The NMC is a Statutory body established in terms of the National Monuments Act to preserve the historical and cultural heritage of South Africa.

The NMC believes that conservation is most effective where the local authority takes the leading role through the following activities:

- Planning for conservation by means of development policies.
- Creating incentives which encourage owners to conserve and maintain their buildings.
- Retain valuable buildings and features by renovating rather than demolition.

2.6.2 Environmental Planning Professions Interdisciplinary Committee (EPPIC)

With the promulgation of the Environmental Conservation Act in June 1989, EPPIC's role has become increasingly important. EPPIC's function in terms of its Strategic Plan is an intermediary between central government and the professions and professionals. Integrated environmental management is a systematic approach to ensure the structured inclusion of environmental considerations in decision making at all stages of the project development process.

2.6.3 Simon van der Stel Foundation

The Simon van der Stel was constituted in 1959 to fulfil a similar role so that played by the National Trust in Britain to preserve old historical buildings and structures for posterity.

2.6.4 Witwatersrand Heritage Trust (WHT)

The WHT is the umbrella body for urban conservation specifically on the Witwatersrand.

All the member bodies are dedicated to conserving the urban heritage for all South Africans.

The founding members of the WHT are the Parktown and Westcliff Heritage Trust, Johannesburg Historical Foundation, Rand Pioneers, Sandton Historical Association, South African Archaeological Society, Institute of Architects Heritage Trust, the Liaison Committee of the National Monuments Council and Johannesburg City Council, and the Braamfontein Spruit Trust.

Similar heritage trust organisations exist in other provinces.

2.6.5 The Role of Johannesburg City Council (JCC)

The JCC has used its powers to protect and preserve part of that heritage largely by creating incentives to assist owners. The transfer of bulk from the Rand Club has made demolition there uneconomical; special relaxation on an adjoining site saved Markhams, the conversion of the Old Newtown Market into a theatre complex and museums; and the conditions of sale for the Electricity Site retaining the Turbine Hall, Boiler House and other buildings are examples of the different techniques which have been applied.

The City Council is hampered by certain deficiencies in the Town Planning and Townships Ordinance by the threat of claims for compensation and by the possibility of being overruled with regard to rezoning township applications and the criteria to be applied to building plans.

When work is proposed to an historic building clearance is required from the Local Planning Authority if the character of the building is of special architectural of historic interest and would be affected. This system, which was intended to control work by the public, would break down if it became too involved in detail. In practice the Planning Authority should be consulted only over the more significant changes.

2.6.6 The Law

The National Monuments Act was amended in 1986 to allow for various forms of protection. It also included the local authority or the planning authority for the first time.

The forms of protection for immovable property are:

- Declaration as a National Monument
- Provisional declaration as a National Monument
- Listing in the National Register

- Declaration of Conservation Areas
- Historical Sites
- Archaeological Sites

Declaration as a National Monument

This is the ultimate form of protection. No alteration to the fabric or to the use may be effected without the consent of the NMC. It does not affect ownership or allow the public right of access. The declaration is made by the Minister and is registered against title deeds.

The local authority is not formally involved in the declaration of a National Monument, although the NMC notifies the City Council of such decisions.

In addition, the Environment Conservation Act, (Act No. 73 of 1989), makes provision for the drawing up of reports on the impact on the environment of activities identified and prohibited in terms of Sections 21 and 22 respectively. These reports will evaluate the impact such development may have on the natural and man-made environment, and this includes archaeological sites.

Local and regional authorities also have regulations requiring evaluation of the possible effects that rezoning and development schemes may have on the environment, including the cultural heritage, but it needs more public awareness to see that these regulations are implemented.

There is presently considerable public recognition of the damage already done to the built environment by vandalism and the failure of the general public and developers to appreciate the importance of preserving the built environment.

2.7 The Role of Consultants

It is important that the role of the engineer is considered in close association with the role of the architect and the developer, since the renovation of an old building is technically and economically dependent on the close co-operation between all consultants.

The developer should recognise and understand the economic aspects of conservation which should not be considered only as the optimisation of land values and rental structures.

For building structures, the team should be led by an architect, skilled in conservation work

The redevelopment and conservation of historic precincts and buildings could have a major positive economic benefit to the developer and the city in the allowing respects:

- Refurbishment of historic buildings is often more economical than reconstruction and creates a focus for environmental improvement.

- With upgrading and environmental improvement the surrounding land values are substantially increased adding considerably to the Council's rates income in that area.

- However, the local authority needs to provide sufficient incentives for the preservation and upgrading of old buildings which are not necessarily of historic value particularly where the costs of refurbishment exceed the economic value of the building.

Also, the architect and the engineer have to understand the historic context of the building and be aware of particular architectural and structural merits which are important to preserve.

The structural engineer can play a significant role in recognising the requirements for assessing the condition of the building structure, materials and finishes. The engineer must fully understand the basic stability concepts of the structure and the properties of the materials used at the time of construction.

Appraisal and renovation of historic structures is rapidly becoming an important discipline within the field of structural engineering and calls upon the experience and knowledge of a broad range of specialities including structural analysis, material technology, diagnosis of problems and repair technology.

The possible objectives in a systematic approach to the preservation of historic structures centre around the structural adequacy of the building and the need to ensure a future lifetime performance for the refurbished structure.

The procedures should be undertaken systematically in a very different sequence from the design of new buildings.

In the economic assessment of the condition of an old structure the engineer can define the extent of remedial or strengthening work required which could have a very significant bearing on the selection of buildings to be preserved.

Finally, the engineer must satisfy the conditions of public safety which does not necessarily mean strict adherence to Codes of Practice - but rather the use of sound judgement in the choice of acceptable standards of safety taking into account the history of the structure.

2.8 References

1. **Appraisal of Existing Structures,** Institution of Structural Engineers, (Jul 1980)
2. **Guidelines for Structural Condition Assessment of Existing Buildings,** American Society of Civil Engineers, ASCE Standards AN SI/ASCE 11.90, (Aug 1991)
3. **Inspection and Maintenance of Reinforced and Prestressed Structures,** Thomas Telford (FIP Publication)
4. Van der Waal, G.M., **From Mining Camp to Metropolis,** Chris van Rensburg Publications, (1987)

SECTION 3.0 : THE SYSTEMATIC PROCESS OF APPRAISAL

SECTION 3.0 : THE SYSTEMATIC PROCESS OF APPRAISAL

3.1 Objectives of Establishing a Systematic Procedure

The objective in preparing a systematic procedure and flow diagram is to represent graphically a complicated process which is both iterative, cyclical and follows a logic sequence of decision taking steps.

The flow diagrams are not necessarily complete for all structures and the precise procedure for the assessment of individual structures should depend on the professional engineer in control of the investigation.

Also, the condition assessment for structures in South Africa is very different from the older and more historic structures in Europe and consequently the procedures developed in this dissertation are original in this respect.

The importance of establishing the correct procedure of appraising old structures has been recognised and several flow diagrams have been prepared by various authorities. The essential differences in the process of appraisal compared with the design of new structures is reflected in these flow diagrams and is summarised in Table 3.1.

Table 3.1 Appraisal Compared to New Design

APPRAISAL PROCEDURE	NEW DESIGN PROCEDURE
Inspections & Survey	Concept Designs
Evaluation	Approvals
Forensic Engineering	Detail Design
Remedial Construction	Tender and Construction

This table shows the basic stages in the appraisal procedure which is in effect a form of 'Reverse Engineering' - commencing with an analysis of the built structure and then evaluating the general conditions and the degree of deterioration and specifically determining the reserve of strength in the old structure.

The required levels of safety factors will then determine the extent of reconstruction. In the case of new designs the procedure is well established and is controlled by standard design methods and Codes of Practice where the properties of the materials are specified and tested to achieve the required structural strengths.

All structures deteriorate with time and the typical history of the relative durability and strength is shown on Fig. 3.1. The need to appraise the condition of the structure at the right time can influence the rate of deterioration and the economic choice of whether to preserve the structure or renovate.

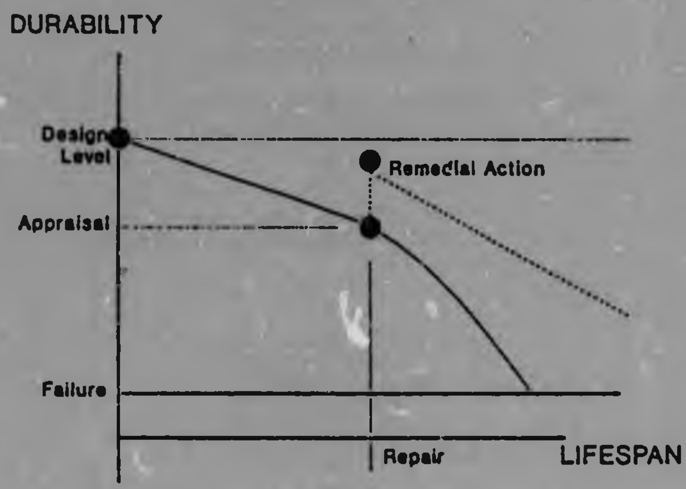


Fig. 3.1 Durability Compared to Lifespan

The lifespan of a reinforced concrete structure depends on many factors such as exposure conditions, durability of materials, strength properties and loading history and the adequacy of the original design. Most building owners assume that the structure will not require much maintenance and consequently most old structures have not been checked except under special circumstances such as major alterations or change of ownership. In fact, the ability of the structure to provide adequate level of service has become a major consideration in recent years and the benefits of regular appraisal can prolong the economic life of the structure.

3.2 Review of Published Procedure Flow Diagrams

The following flow diagram illustrated in Fig. 3.2 has been reproduced from Ref [2]. Although this flow diagram contains the elements of the basic procedures it does not distinguish between investigative or inspection activities and diagnostic procedures. In addition there is no detailed indication of what is meant by 'preliminary evaluation' or 'judgmental phase'. These points have been addressed in the more elaborate flow diagrams presented later in this dissertation.

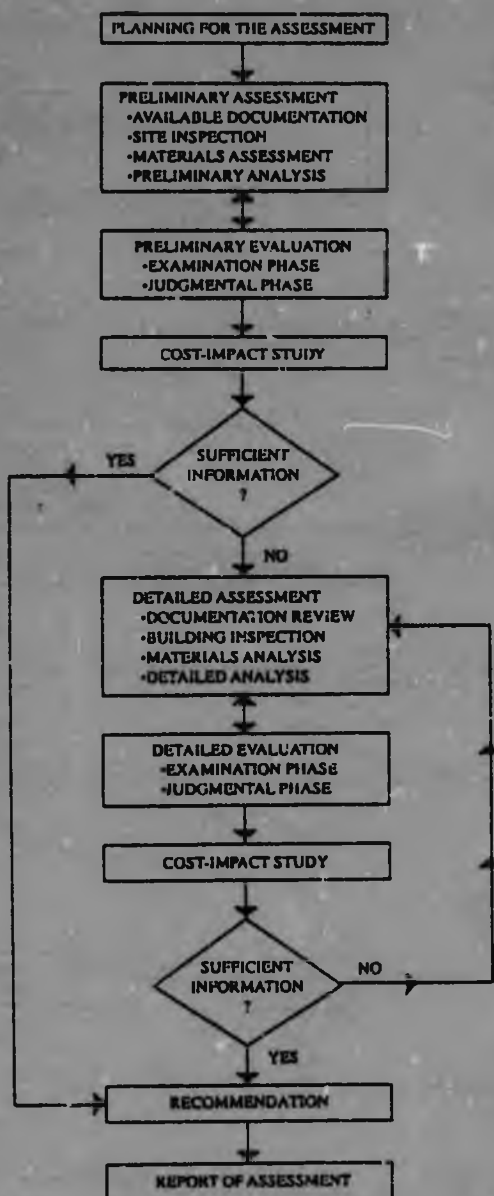


Fig. 3.2 Structural Assessment Flow Diagram

An alternative flow diagram illustrated in Fig. 3.3 has been reproduced from Ref [1].

This procedure is more elaborate and is based on detailed structural analysis rather than assessing the structure using more general criteria such as historic importance, economics of repair or predicting future lifespan.

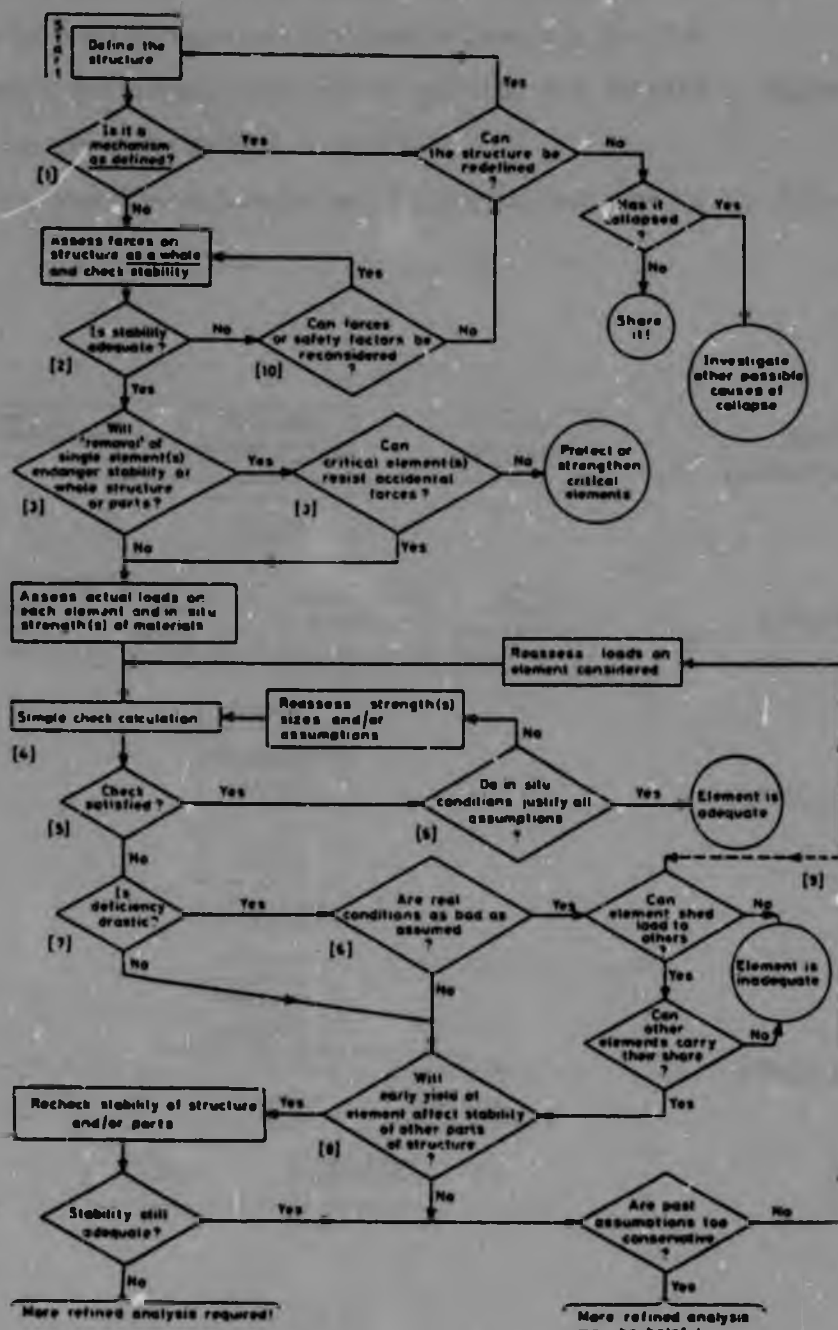


Fig. 3.3 Structural Appraisal Flow Diagram

3.3 Determination of New Procedure Flow Diagrams

The main shortcomings of the previous flow diagrams is that they are generally too elaborate for the typical structures subjected to appraisal in Southern Africa and also the specific problems which need investigation are dependent on local materials and construction methods which are not as sophisticated as the older monuments or structures in Europe or the USA.

Taking into account the previous comments on published flow diagrams an original procedure has been proposed for typical structures in South Africa.

The proposed new overall procedure can be considered in four basic steps as follows and is shown on Fig. 3.4.

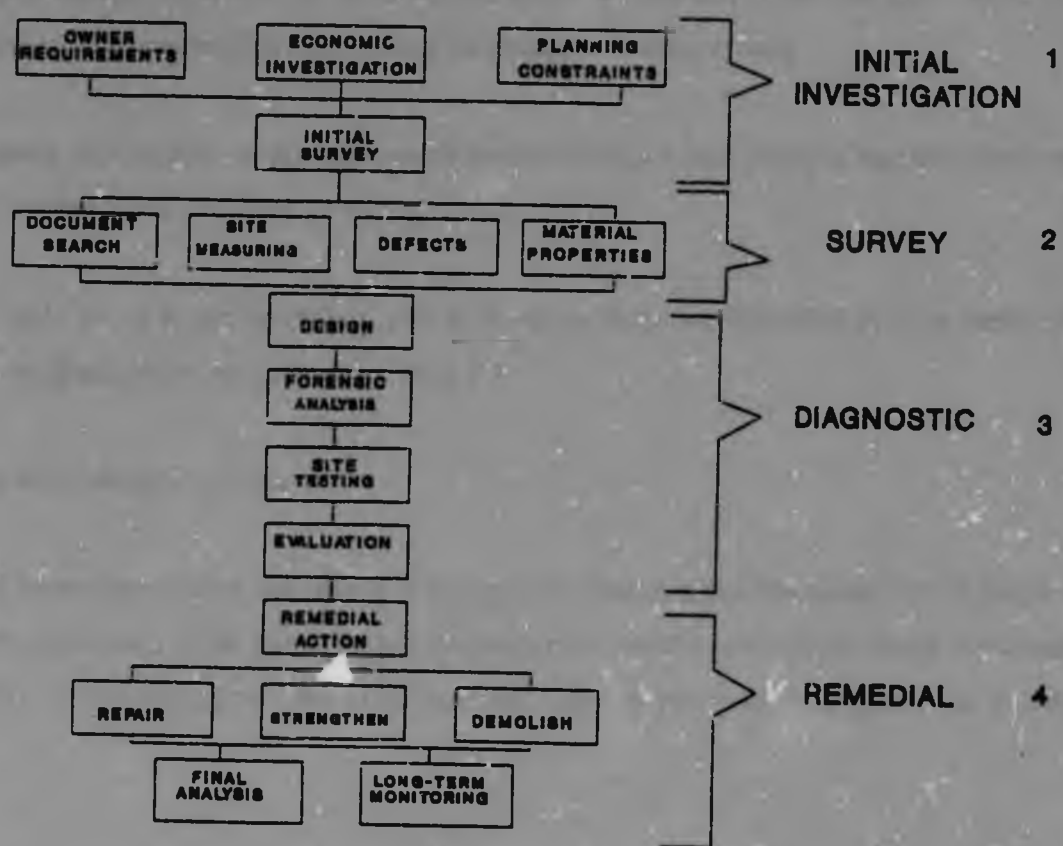


Fig. 3.4 Proposed Appraisal Procedure and Flow Diagram

3.4 Key Stages in the Procedure

Each of the blocks in the procedure diagram represent comprehensive activities which should also be carried out in a systematic approach. However, no procedure diagrams can provide complete answers and in every investigation individual experience and judgement are major factors.

In the proposed appraisal procedure and flow diagrams that follow, groups of activities are indicated by Key Words in a rectangular block. For each of these blocks a short description of the procedures and activities is given in the text. However, in order not to confuse the procedural steps full technical aspects of the main activities are considered in detail in later Sections of this dissertation.

A series of investigations should be carried out to obtain documentation and site visits should obtain all information on the material properties and the structural stability system.

The process is also iterative in that information obtained during a later phase of appraisal could result in a more detailed investigation of an earlier activity.

The four basic stages in the procedure used in this dissertation are described in more detail below with the overall procedure as illustrated on Fig. 3.4.

3.5 Initial Investigation Stage

The initial inspections carried out during this stage will determine the immediate risk of failure and the historic importance of the structure and deal with other critical factors such as the economics of preservation or reconstruction. An initial appraisal stage as proposed by Beckman is shown on Fig. 3.5.

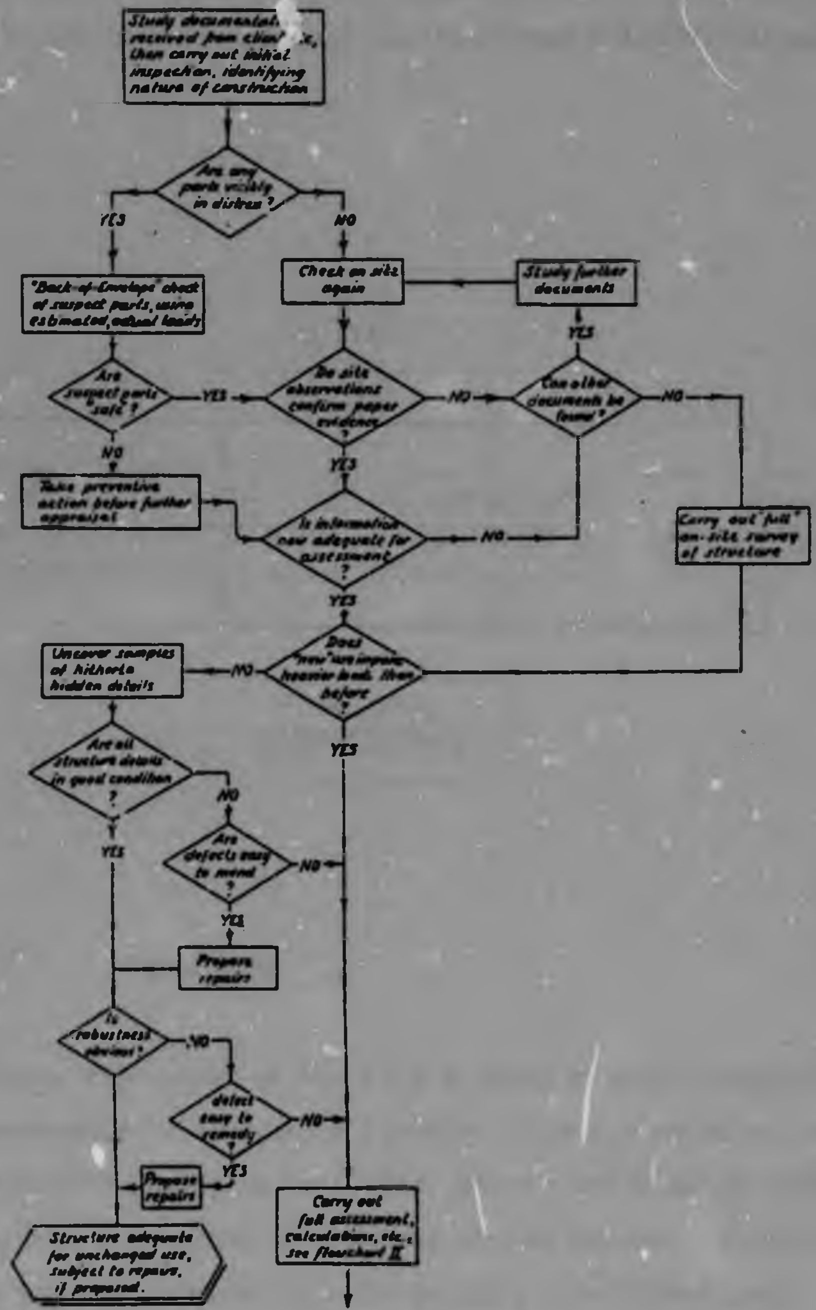


Fig 3.5 Path of Initial Appraisal by P Beckman

The initial appraisal procedure shown on Fig. 3.5 is considered too elaborate for most structural appraisals carried out in South Africa and consequently a simpler procedure has been suggested covering the basic requirements of the building owner, the local authority planning constraints and an economic investigation.

On completion of the initial investigation a definite decision should be made on whether to proceed with the full appraisal as considerable expenditure could be involved in the following stages.

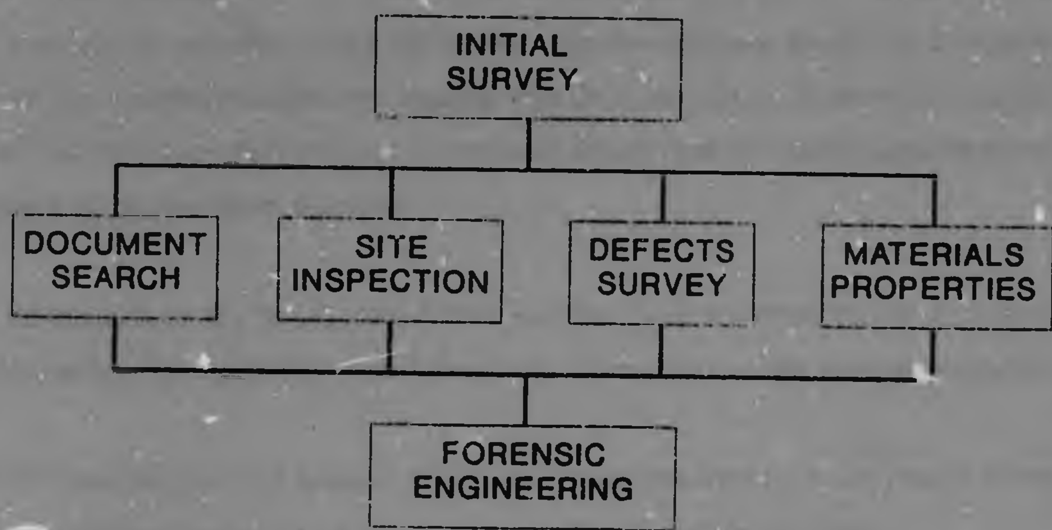


Fig. 3.6 Survey Stage

The object of the survey stage shown on Fig. 3.6 is to obtain as much information as possible regarding the current condition and behaviour of a structure. Initially, a preliminary reconnaissance is undertaken to establish the condition of the structure generally and to identify problem area, for instance, finishes may have to be removed to expose the structure for access. An important aspects of the survey stage is the perusal of all documentation pertaining to the original design.

With reference to Fig. 3.6 each of the main activities in the Survey Stage is described below.

3.6 Survey Stage

3.6.1 Documentation and Archives

This would include design specifications, construction drawings calculations and construction records. The documents will form the basis for obtaining the geometry and layout of the structure and to ascertain the prevailing design philosophy Site measurements to confirm dimensions, levels and layout are nevertheless imperative, together with the establishment of current loading particulars. At the end of the survey stage a record of measured defects must be available and test results giving the strength of the constituent materials.

Useful information on the design, construction and history of the structure can often be obtained from documents prepared for the original design and construction and for subsequent modifications.

The initial reconnaissance and available documents provide the basis for a dimensional survey which should include measurements of the site, building levels and structural elements.

The information required for the first stage of a structural appraisal includes a comprehensive knowledge of both the construction and the conditions of service to which it is likely to be subjected.

3.6.2 Inspections and Preliminary Testing

The scope of the survey must include all relevant information about geometry and overall [illegible]ion of structure. Before a survey is put in hand, the engineer should make a reconnaissance to [illegible]lish conditions generally and to decide which finishes have to be removed to expose the structure.

Inspections of structures on a regular basis is a crucial aspect of the procedure for preservation in that regular maintenance can justify the economics and prolong the life of the structure. As an example in a recent report about 39 percent of all highway bridges in the United States can be classified as deficient in terms of their inspection programme.

A comprehensive publication Ref. [5] is available providing guidance on all aspects of surveys and inspections for buildings and structures.

Recently, a four year rehabilitation programme has been planned for Johannesburg's busy M2 motorway. This will include an elaborate inspection reporting and maintenance system.

The inspection system should be standardised for different types of structures and materials and involves a considerable knowledge base of the common causes of deterioration which can be evaluated on a statistical basis using Markov chains as described in Ref [6]. However, to obtain useful data from this system a considerable number of inspections needs to be compiled which is not currently available for South African structures or old buildings.

3.6.3 Defects Survey

It is important to record all the defects observed during the Survey Stage. If a major structural problem is observed temporary propping and strengthening should be immediately undertaken to ensure safety while further investigations are carried out. In addition a maintenance programme should be undertaken to prevent further deterioration of the building or structure.

3.6.4 Materials Properties

If the original records of the original construction are available then the properties of the materials used can be ascertained. However, in most cases few records exist and consequently the physical properties will have to be assessed by means of testing taking into account the time-dependent changes likely to occur in most structural materials.

3.7 Forensic Engineering Stage

Following the completion of the Survey Stage the main activitiy of structural appraisal should be undertaken which includes the procedures illustrated in Fig. 3.7.

The definition of forensic engineering used in this dissertation is the investigation of inherent problems in existing structures by means of inspection, survey and testing followed by diagnosis, evaluation, estimation of life-span and repair technology.

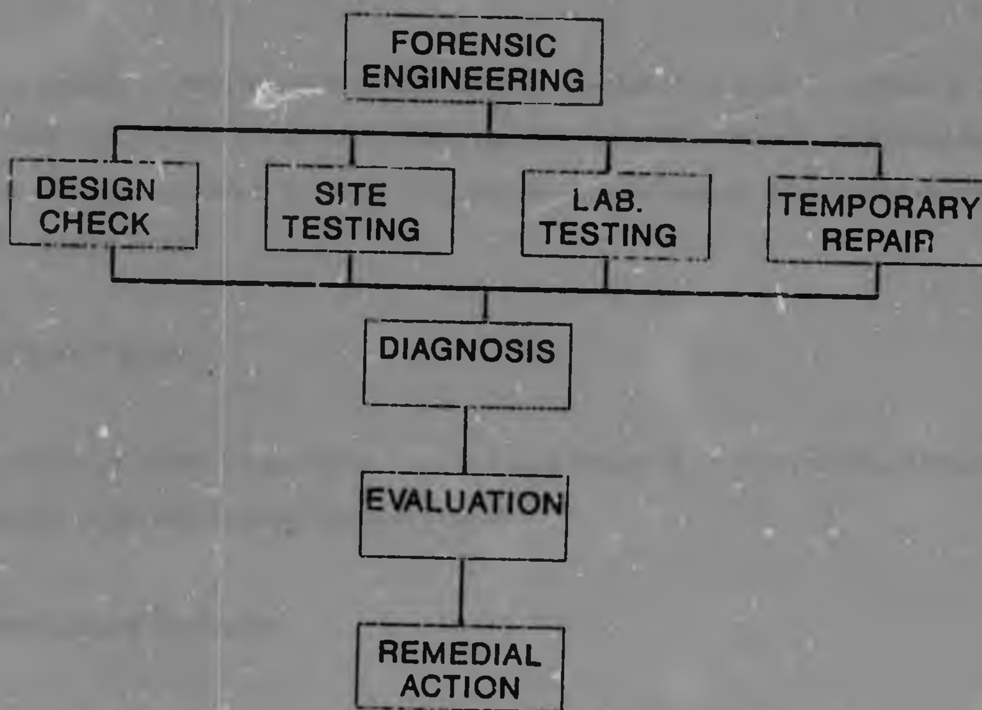


Fig. 3.7 Forensic Engineering Stage

3.7.1 Structural Design Check

If the original structural analysis and calculations are available these should be studied and analysed in order to understand the original loading and materials specifications. Further structural analysis and design checks should be made of the load carrying capacity of the structure and the margins of safety by calculation using the available information on actual loads and the size and strength of the materials and components. The choice of partial factors of safety is reviewed in more detail in Subsection 5.3 of this dissertation.

In particular, the inherent stability and the adequacy of the construction should be considered. The first calculation will practically always be a simple conventional design calcualtion.

3.7.2 Site and Laboratory Testing

Testing is an expensive operation and should only be undertaken in order to confirm a suspected problem or defect and only in the situation where the cost of remedial work is very dependent on the results of the testing programme. In many structures the costs of testing can be more expensive than the costs of remedial work!

3.7.3 Temporary Repair

As the reconstruction of the structure can be over a long period of time it will often be necessary to ensure the safety of the structure by temporary rapair.

3.7.4 Diagnosis and Evaluation

As these are the most critical procedures in the proposed structural appraisal system detailed procedures are set out in Section 4.0 of this dissertation which deals specifically with the diagnosis and identification of problems in structures.

The diagnosis of inherent problems in old structures is considered in four groups as follows:

- Structural: This relates to the design and analysis of the structure which give an indication of the state of stress and deformations in the structure under loading.

- Durability: The materials of construction are subject to deterioration with time and the diagnosis of this group of problems is illustrated in more detail as part of the Case Study in Section 7.0 of this paper.

- Movement: Deformations and subsidence, temperature and creep movements occur in all structures and become evident as a separate group of problems which can be diagnosed.

- Construction: Often eccentricities and locked-in stresses result from inadequate construction. Also, alterations and additions can lead to major problems at a later stage.

3.7.5 Residual Life Prediction

As part of the evaluation process it is critical to assess the residual life of the structure by prediction of the degree of deterioration of the structure and a knowledge of the materials, original design and past history. The rate of loss of structural strength is determined by the rate of corrosion for reinforced concrete and steel structures and this can be assessed.

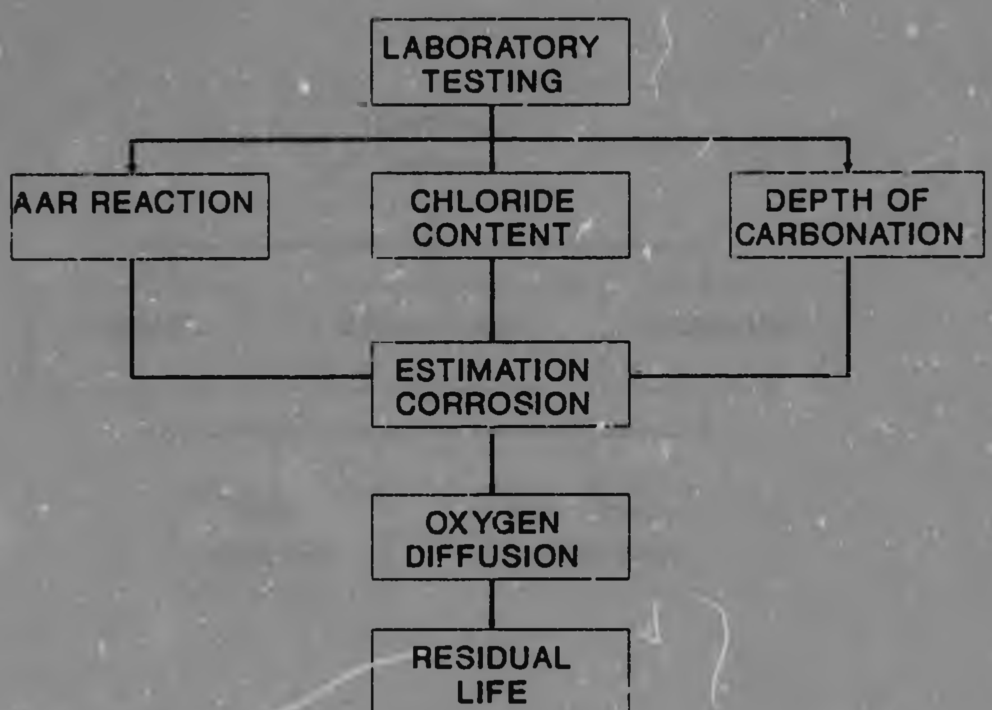


Fig. 3.8 Residual Life Prediction

At a seminar on THE DESIGN LIFE OF STRUCTURES, Ref. [7], it was observed that pre-1939 buildings and structures have generally performed better than later buildings.

The suitability of the structure for further long-term use should be considered in terms of compliance with the latest design codes of practice after remedial work has been completed.

3.8 Remedial Action Stage

The appropriate remedial action will depend on the evaluation of the underlying problems which caused the defects observed and the deterioration of the structure. The procedure is illustrated on Fig. 3.9 below.

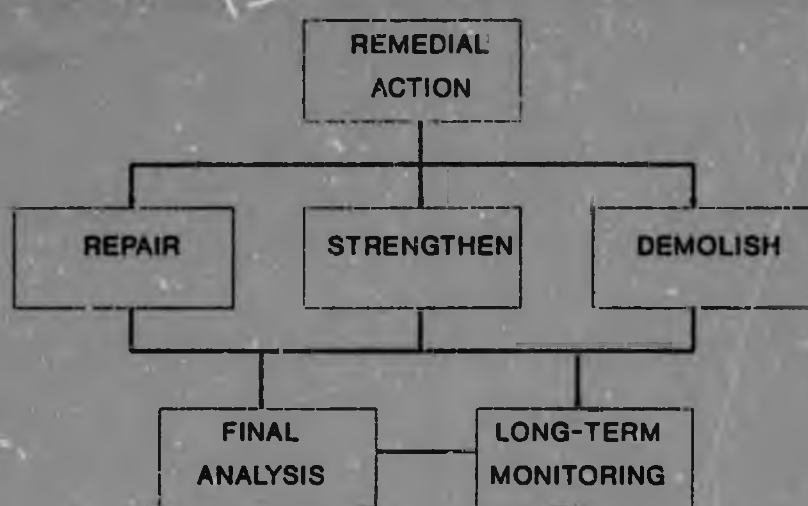


Fig. 3.9 Remedial Action Stage

Further detailed information on Repair Technology is included in Section 6.0 of this dissertation in order to provide details of repair systems.

3.9 References

1. **Appraisal of Existing Structures,** Institution of Structural Engineers, (Jul 1980)
2. **Guidelines for Structural Condition Assessment of Existing Buildings,** American Society of Civil Engineers, ASCE Standards AN SI/ASCE 11.90, (Aug 1991)
5. Institution of Structural Engineers, **Guide to Surveys and Inspection of Buildings and Similar Structures**, London 1991.
6. M Cesare et al, **Modeling Bridge Deterioration with Markov Chains,** Journal of Transportation Engineering Vol 1:8 No 6, 1992.
7. Institution of Structural Engineers, **The Life of Structures,** Seminar 24-16 April 1989, Brighton.

SECTION 4.0 : FACTORS AFFECTING THE SERVICEABILITY OF OLD STRUCTURES

4.1 Age-related Problems in Structures

4.2 Identification of Primary Structural Problems

4.3 General Diagnosis of Problems in Structures

4.4 Serviceability Problems in RC Structures

4.5 Diagnosis of Material Problems in RC Structures

4.6 Problems in Steel and Cast Iron Structures

4.7 Durability of Timber Structures

4.8 Problems in Masonry Structures

4.9 References

SECTION 4.0 : FACTORS AFFECTING THE SERVICEABILITY OF OLD STRUCTURES

4.1 Age Related Problems in Structures

Before starting remedial or refurbishment work it is important to identify the underlying causes of defects and deterioration in the structure under consideration in order that an appropriate and effective repair and strengthening technique may be selected. The proposed expert system contains a brief introduction to assist engineers and those responsible for maintenance in identifying likely causes based on the factors influencing the serviceability and the residual life of the structure.

Although considerable attention has been devoted in this dissertation to concrete, the most widely used construction material in Southern Africa, the age-related problems in structural steel, timber and masonry have also been considered without undertaking the full extent of the diagnostic process as this is considered a subject for further research.

The diagnostic procedures developed as part of this dissertation are entirely original and are based on the logical procedures as defined below.

4.2 Identification of Primary Structural Problems

The first important step is to distinguish between symptoms which are derived from visual observations and test results and the underlying primary causes of the problems. In the diagnosis of primary problems the critical symptoms have been identified according to four groups of primary causes of problems.

The grouping and identification of problems and symptoms is a unique research aspect of this dissertation based on extensive literature dealing with structural failures and materials technology relating to diagnostic procedures.

The diagnosis of inherent problems in old structures is considered in four groups, each of which is defined as a separate diagnostic subsystem.

- Structural Problems: This relates to the design and analysis of the structure which give an indication of the state of stress and deformations in the structure under loading. The overall stability of the structure as a whole has to be considered as many of the primary problems can be attributed to causes intrinsic in the overall stability of the structural system.

- Materials Problems: The materials of construction, finishes and sealants are subject to deterioration with time and the diagnosis of this group of problems for reinforced concrete is illustrated in more detail as part of the Case Study in this dissertation. This group would include fire, flood and explosion damage to materials.

- Movement Problems: Deformations and subsidence, vibrations, shrinkage, temperature and creep movements occur in all structures and become evident as a separate group of problems which can be diagnosed according to specific symptoms.

- Construction Problems: In many old structures problems arise from faults and built-in eccentricities in the construction, alterations and additions which have been made during the history of the structure.

4.3 General Diagnosis of Problems in Structures

The diagnosis of problems in old or historic structures is dependent on recognition of the differences between the symptoms and the primary underlying causes of the problem.

In most cases of diagnosis, the primary cause is obvious and can be quickly identified by experienced engineers. However, a systematic procedure of forensic engineering can help in correct diagnosis and provide a comprehensive knowledge base and advice on testing methods, interpretation of results and remedial measures.

The basic diagnostic procedure is illustrated in Fig 4.1.

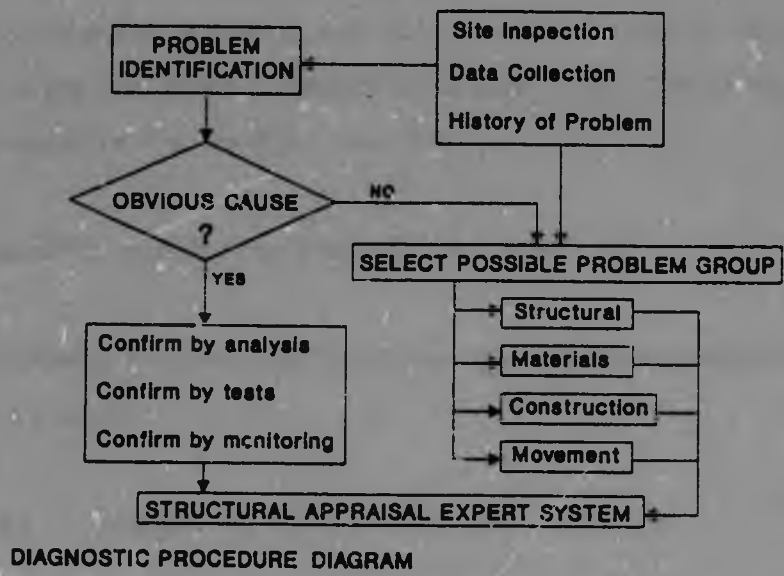


Fig. 4.1 Diagnostic Procedure Diagram

This general diagnostic procedure outlined above needs to be more specific when identifying problems in old structures constructed with traditional materials such as timber, masonry, cast-iron, steel and concrete. Since the complexity of diagnosis in different materials is very elaborate only a comparative summary of the specific material primary problems and related symptoms are considered and the Case Study in this dissertation illustrates in more detail the diagnosis of materials problems in reinforced concrete.

Diagnostic procedures should follow a basic logic system which is aimed at narrowing down the large number of possible causes of problems.

- Directly related symptoms to problems based on observations and tests. These are critical symptom resulting in obvious straightforward diagnosis.

- Identification of the most probable group of one of four primary groups of problems based on experience and judgement and then verification of the diagnosis.

- Where the diagnosis has not met the above criteria which is the case in most old structures then a more comprehensive systematic diagnostic procedure should be followed relating all the symptoms to the most probable primary cause based on a statistical expert system approach which is described in more detail in Section 7.0.

4.4 Grouping of Serviceability Problems in RC Structures

The grouping of primary problems in RC structures which affect the serviceability of the structure is shown in Table 4.1 below:

Table 4.1 Grouping of Primary Problems in RC Structures

STRUCTURAL PROBLEMS	MATERIALS PROBLEMS IN RC	MOVEMENT PROBLEMS	CONSTRUCTION PROBLEMS
Incorrect Design	Excess Chlorides	Creep	Alterations
Loading Changes	Excess Carbonation	Shrinkage	Additions
Instability	Inadequate Cover	Ground Subsidence	Eccentricities
Deformations	A A R	Temperature Changes	Joints

4.4.1 Diagnosis of Structural Problems in RC Structures

Specific structural problems can usually be identified by visible signs of distress and check calculations of the existing stresses in the structure.

Crack patterns indicate overstressed sections and indicate the direction of principal tension forces and relative deformations.

Typical crack patterns in beams and walls are shown on Fig 4.2 and crack pattern identification can be incorporated in the proposed Expert System to facilitate diagnosis of structural problems.

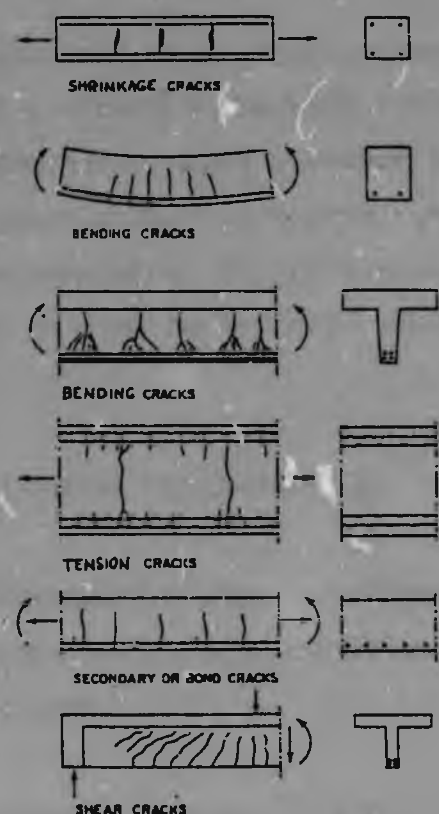


Fig 4.2 Types of Structural Cracking

4.5 Diagnosis of Materials Problems in RC Structures

The correct diagnosis of primary materials problems in reinforced concrete structures is dependent on the visual examination of the structure and the test results available.

In order to develop the concepts and diagnostic principles set out in the previous section 4.3, this chapter on the materials deterioration in reinforced concrete has been researched in greater detail in order to illustrate an actual case study with the application of an Expert System.

When considering repair of a deteriorated concrete structure, the cause of the primary problem should first be confirmed, as the nature and extent of the repair methods will be determined by the cause and consequently the effectiveness of the repaired structure will depend on a correct diagnosis.

The first step in this system is to identify the primary non-structural groups of problems which result in corrosion of reinforcement or deterioration of concrete. Corrosion due to sulphate attack on the concrete can be caused by atmospheric pollution or structures below ground exposed to sulphate-bearing ground water. However, as this is not a common problem in South Africa no further consideration has been given to this cause. Although there are many combinations or groups of primary causes of corrosion, this system has been initially restricted to diagnosis of the following four groups:

- Excess Chloride Content (Notation : CHLORIDE = CH)

  The presence of high concentrations of chloride ions migrate to the steel surface and cause a local breakdown in passivity irrespective of whether the concrete is fully alkaline or carbonated, resulting in corrosion of the steel.

- Carbonation of the Cover Concrete (Notation : CARBONATION = CA)

  The effect of carbonation of the concrete is to neutralise the alkalinity of the concrete, reduce the concrete pH and change the crystal structure of the cement which leads to corrosion of the steel.

- Inadequate Cover to Reinforcement (Notation : COVER = CO)

  If the cover to the reinforcement is below certain limits and the exposure conditions are severe, corrosion of the steel can occur. Carbon dioxide from the air combines with the alkaline calcium hydroxide of the cement to form neutral calcium carbonate which has no protective value to the steel.

- Alkali Aggregate Reactions (Notation : AAR = AA)

Alkali-aggregate reaction causes the aggregate particles to expand exerting a bursting force on the localised concrete resulting in map-pattern cracking which can expose the steel to corrosion.

Summary sheets for each of the above primary concrete materials problems are given in sections 4.5.1 to 4.5.4 which summarise the symptoms, assessment and references.

4.5 Diagnosis of Material Problems in RC Structures

4.5.1 Summary Sheet for the Assessment of Corrosion due to Excess Chloride

Visible Symptoms

1. Cracks are generated in cover concrete due to corrosion of reinforcement along the lines of reinforcement steel.
2. Delamination, spalling and peeling off of cover concrete.
3. Reduction in cross-section area of reinforcement and strength of concrete.
4. Appearance of brown rust staining.

Tests

1. Measurement of chloride ion content as % of cement mass
2. Chloride ion diffusion tests
3. Measure the electrochemical potential of the reinforcement
4. Check cover to steel and permeability.
5. Determine pH value of cover concrete.

Assessment

SEVERITY RATING	RANGE (% of cement mass)
Low or no problem	< 0,2%
Moderate problem	0,2% - 0,6%
Severe problem	> 0,6%

References

1. Fulton P. 192 Ref [8]
2. BRE Digest 264
3. SABS 0100 Part 2 (3)

4.5.2 Summary Sheet for the Assessment of Corrosion due to Carbonation

Visible symptoms

1. Cracks and spalling due to corrosion of reinforcement.
2. Appearance of rust staining.
3. Damp, moist exposure conditions.

Tests

1. Test freshly broken concrete with phenolphtholein in alcohol.
2. Measure depth of carbonation in mm.
3. pH value of cover concrete.

Assessment

SEVERITY PROBLEM	FREE DEPTH OF CARBONATION (cover depth - depth carbonation)
No problem	> 15 mm
Moderate	5 - 15 mm
Severe	< 5 mm

References

Fulton P.453 432-437 Ref [8]

4.5.3 Summary Sheet for the Assessment of Corrosion due to Insufficient Cover

<u>Visible Symptoms</u>

1. Cracks and spalling due to corrosion of reinforcement.
2. Appearance of brown rust staining.
3. Damp or moist exposure conditions

<u>Tests</u>

1. Measurement of concrete cover depth by Covermeter in mm
2. pH value of cover concrete.
3. Moisture conditions of concrete surface.

<u>Assessment</u>

SEVERITY PROBLEM	COVER DEPTH
No problem	> 25 mm
Moderate	10 - 25 mm
Severe	< 10 mm

4.5.4 Summary Sheet for the Diagnosis of Alkali-Agregate Reaction

Visible Symptoms

1. Indications of excess moisture present.
2. Presence of alkali-silica gel.
3. Typical surface map-cracking indicating expansion of concrete surface.
4. Damp and moist exposure conditions.

Tests

1. Analysis of concrete (estimation of mix proportion, alkali (Na_2O, K_2O), chloride content, depth of carbonation.
2. Aggregate tests (type of rock, ratio of composition, grain size analysis for each type, investigation of each component mineral by powder X-ray diffraction method, chemical component analysis, mineralogical analysis).
3. Analysis of extracted gel from reacted aggregate (observation of gel using SEM, investigation of the elements composing it using EPMA, chemical analysis of extracted gel).
4. Expansion test of cores (measurement of change in length at 20°C and RH 100%, estimation of residual expansion under the accelerating condition of 40°C and RH 100%).
5. Potential reactivity test on aggregate in accordance with provisions of ASTM.

Assessment

	HIGH RISK	MODERATE RISK	LOW RISK
Alkali Content	> 3,8 kg/m³	1,8 - 3,8 kg/m³	< 1,8 kg/m³
Free Expansion	> 0,08%	0,04% - 0,08%	< 0,04%

References

Fulton P.484 Ref [8]

4.5.5 Identification of Major Symptoms and Test Results

The second step in this diagnostic expert system is to identify the major symptoms or laboratory test results which can identify the primary problem groups as previously defined above. The number of major symptoms has been restricted to eleven for practical purposes and these are groups as follows:

Visual Symptoms:

	Notation	Units or Description
- Exposure conditions, moisture content, relative humidity	Fm	Descriptive or RH%
- Surface texture of concrete, exposed aggregate, porosity	Fs	Descriptive
- Crack pattern, line cracks, spalling, map-pattern cracking	Fc	Descriptive

On-Site Tests:

- Depth of cover using COVERMETER testing or equivalent	Fo	mm
- Depth of carbonation using PHENOLPHTHALEIN testing	Fd	mm
- Crack widths measured by micrometer	Fw	mm
- Electro chemical potential of reinforcement	Fe	

Laboratory Tests:

- pH value of the concrete cover	Fp	Number
- Chloride content of the concrete	Fh	% of cement mass
- Alkali content of the concrete	Fa	Kg/m^3
- Free expansion tests of core samples	Fx	% Strain

4.5.6 Database of Range of Results

The third step in this system is to obtain sufficient data to establish a database of the range of symptoms and test data based on local conditions and grouped according to the risk of corrosion to reinforcement or deterioration of concrete. Part of this database is shown on Table 4.2. In addition the relative risk factor on a scale of 1 to 9 is indicated. The parameters of Table 4.2 are primarily based on Ref [8].

Table 4.2 Summary of Range of Data Related to Risk (RF = Risk Factor)

SYMPTOMS, TESTS RESULTS	NOTATION	HIGH RISK	RF	MODERATE RISK	RF	LOW RISK	RF
Exposure	Fm	RH > 90%	9	RH 60% - 90%	6	RH < 60%	3
Crack Pattern	Fc	Large, spalling	9	Fine cracks	4	No cracks	1
Cover Depth	Fo	< 10 mm	8	10 - 25 mm	4	> 25 mm	1
Free of Carbonation Depth	Fd	< 5 mm	8	5 - 15 mm	4	> 15 mm	1
Crack Width	Fw	> 0.3 mm	8	0.1 - 0.3 mm	5	< 0.1 mm	1
pH Value of Cover	Fp	< 8.0	8	8.0 - 12.0	5	> 12.0	2
Chloride Content	Fh	> 0.6%	8	0.2% - 0.6%	5	< 0.2%	2
Alkali Content	Fa	> 3.8 kg/m³	9	1.8 - 3.8 kg/m³	4	< 1.8 kg/m³	1
Free Expansion	Fx	> 0.08%	9	0.04% - 0.08%	5	< 0.04%	2

The key factors which determine the diagnostic knowledge-base are shown on Table 4.3 and this data is based on local expert opinion in identifying the primary problems and the significance of the symptoms or test results. Since certain symptoms or test results have greater significance in the diagnostic process, a weighting factor has been introduced.

Table 4.3 Criteria for Diagnosis (Number = Weighting Factor)
(Letter = Risk Significance, High, Low or Medium)

DIAGNOSIS		SYMPTOMS or TEST RESULTS								
		Fm	Fc	Fo	Fd	Fw	Fp	Fh	Fa	Fx
EXCESS CHLORIDES	CH	3 M	2 L	4 H	2 L	2 L	4 H	5 H	2 L	1 L
EXCESS CARBONATION	CA	3 M	3 L	4 H	5 H	2 L	4 H	1 L	2 L	1 L
INADEQUATE COVER	CO	4 H	4 H	5 H	1 L	3 M	4 H	2 L	2 L	1 L
AAR	AA	5 H	4 H	2 L	1 L	2 L	3 M	1 L	4 H	5 H

In order to relate the combination of symptoms or test results to a choice of probable cause it is necessary to establish a Decision Tree or Logic Decision Diagram. This shows the derivation of the diagnostic Logic Decision Diagram can be generated through Quinlan's ID3 algorithm which selects the attributes in order of increasing entropy. This decision tree has been based on the data in Tables 4.2 and 4.3 and a simplified example is shown on Fig. 4.2.

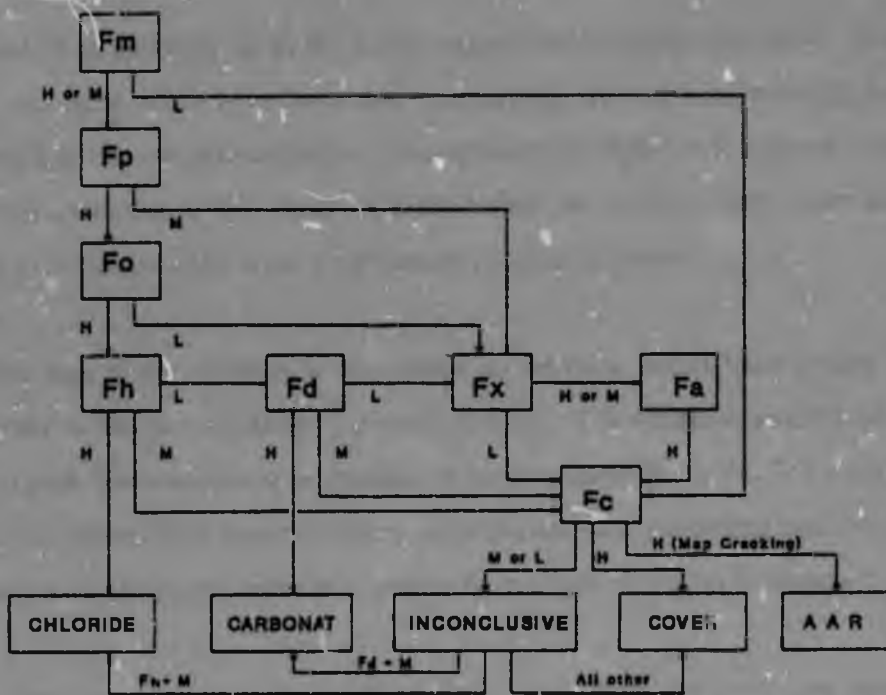


Fig. 4.2 Logic Decision Diagram

The diagnostic system is conditioned to achieving an immediate diagnosis in the case of symptoms or test results which clearly indicate one of the four groups of problems. However, where results are inconclusive the system will evaluate a probability for each of the four possible conclusions and suggest a primary and secondary choice of diagnosis or if insufficient data is available no conclusion will result.

4.6 Problems in Steel and Cast Iron Structures

The use of steel or cast iron in structures built in South Africa was generally confined to bridges rather than buildings which were mostly built of masonry and concrete.

Corrosion is the major cause of deterioration in steel structures and can result in progressive weakening of the structure and finally sudden collapse.

The first essential of an appraisal of an old metal structure is to identify the metal. The three basic varieties of ferrous metal which have been used in structures are cast iron, wrought iron and steel. Wrought iron has a tensile strength similar to its compressive strength but it is prone to delamination. The different characteristics of the metals and the techniques used to form them into structural sections and the joint details often make identification possible by inspection.

Knowledge of the age of the structure is also useful, as the three metals have in turn flourished as structural materials in the past at different periods of time. It is therefore sensible to examine the structure, and to seek documentary or other clues to its age. Sampling in the first instance is needed only to confirm the nature of the material. More extensive and costly sampling and testing is best left until an initial appraisal has shown whether a scheme for reuse or alteration is feasible in principle.

In diagnosing other major problems in steel structures apart from corrosion and identification of material, the visible symptoms will include excess deformations, buckling of principal elements and indications of joint slip. Also the identification of the nature, type and thickness of protective coating is important in appraising the condition of steel structures.

A common problem arising in early steel frameworks is that of identifying an adequate stability system for horizontal loads.

4.7 Durability of Timber Structures

In considering the appraisal of an existing timber structure the first step is to recognise the difference between symptoms of distress and the underlying primary structural problem. In the case of timber structures the appraisal and diagnosis is more straightforward than reinforced concrete since timber structures generally comprise separate elements which can be easily inspected and tested. However, the overall stability system in timber structures can be very complicated if not adequately documented.

4.7.1 Grouping of Primary Problems in Timber Structures

Table 4.4 below is based on the major problems which have been identified in timber structures built in South Africa and researched by the committee responsible for producting SABS 0163.

Table 4.4 Grouping of Primary Problems in Timber Structures

STRUCTURAL	MATERIALS	MOVEMENT	CONSTRUCTION
Incorrect Stress Grading	Excess Moisture	Creep and Shrinkage	Insufficient bracing
Incorrect Design	Insect Attack	Subsidence	Joint eccentricities
Joint Strength	Timber Identification	Joint Slip	

4.8 Problems in Masonry Structures

Problems in masonry structures generally occur due to tension and shear stresses causing cracks in the masonry panels.

4.8.1 Grouping of Primary Problems in Masonry Structures

Table 4.5 below is based on experience in assessing typical problems in many masonry structures built without adequate engineering design and supervision.

Table 4.5 Grouping of Primary Problems in Masonry Structures

STRUCTURAL	MATERIALS	MOVEMENT	CONSTRUCTION
Incorrect Design	Masonry Strength Problems	Temperature	Panel Joints
Panel Fixings	Aggregate Reactions	Subsidence	Eccentricities
Instability	Corrosion of Fixings	Expansion	Site Alterations
Expansion Joints	Mortar Joint Materials	Creep & Shrinkage	Dampproofing

4.9 References

8. Fulton's Concrete Technology, Published by Portland Cement Institute, Revised Edition 1986

SECTION 5.0 : COMPARATIVE STRUCTURAL DESIGN AND ANALYSIS

SECTION 5.0 : COMPARATIVE STRUCTURAL DESIGN AND ANALYSIS

5.1 Introduction to Comparative Structural Design and Analysis

The appraisal procedure for an existing structure is very different from the normal design procedure of an original structure. The entire approach is different and the key differences which are shown on Table 3.1 constitute a system of reverse engineering.

In general the appraisal of old structures depends very largely on the personal experience of the consulting engineer and a knowledge of the history of the building. The diagnostic techniques on the condition of the structure need to be intuitive where symptoms are not readily visible. By comparison, the design procedure for new structures is much better documented and less dependent on the experience of the engineer.

The structural analysis of an existing structure must commence with identification of the main and secondary structural elements which can be particularly difficult if the existing structure has been finished and decorated with architectural features which hide the structure. The modelling of the structure can also be difficult since many older structures were not always analysed and sized to optimise the structure. In particular, the stability of the old structures is often very difficult to ascertain.

In many old structures extensive additions and alterations have taken place and cannot be clearly identified.

The purpose of analysis is to identify the stability system and to determine the existing stresses in relation to the loads carried. The identification of highly stressed elements is of particular importance since the reserve of strength and overall factors of safety depend on knowing the level of stress in critical elements.

5.2 Major Changes to Structural Design Codes

In order to assess the effects of changes in Design Codes Fig 5.1 illustrates the history of the main structural codes over the period 1950 to present.

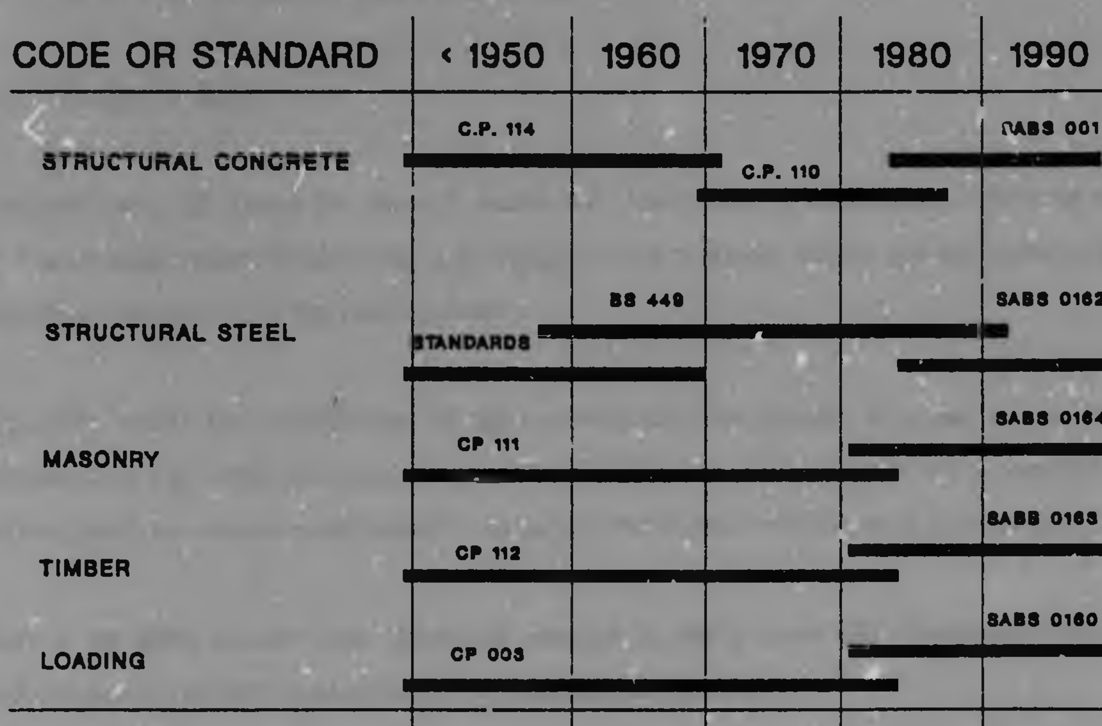


Fig. 5.1 Diagrammatic History of Codes of Practice

The evaluation of the effect on existing structures of changes which have been made to structural design codes since the original design was completed can have significant results in the serviceability of the structure and in the diagnosis of inherent weaknesses.

However, the fact that the structure has been standing for considerable time has to be taken into account and this can be achieved by rechecking the design with adjusted partial factors of safety and revised loading.

With particular reference to Reinforced Concrete three major aspects are reviewed based on the changes between present day codes and earlier codes of practice.

5.2 Major Changes to Structural Design Codes

5.2.1 Design for Shear

In earlier codes the design for shear in beams was determined by establishing a limiting value of permissible shear stress based on the cube strength of the concrete. Above this stress level the entire shear force was carried by the reinforcement.

In modern codes the contribution of the concrete and the amount of shear reinforcement is determined on a proportional basis taking into account both the cube strength of the concrete and the percentage of main tensile reinforcement. In general more shear reinforcement is required in beams.

Shear in flat slabs has also been drastically changed in recent codes and considerably more shear reinforcement is required in accordance with modern design codes.

Consequently, it is likely that old RC structures will not have sufficient shear reinforcement to satisfy modern code requirements.

5.2.2 Design for Slender Columns

An example of the comparison in design of slender columns is given in Table 5.1 on the following page based on Ref [9].

Table 5.1 Comparison of Column Design CP114 and CP110

Column Size (mm)	Length (m)	Type	End Conditions	% Reinf.	CP 114			CP 110			Ratio:
					Slenderness Ratio	Reduction Factor	Working Capacity (KN)	Slenderness Ratio	Eccentricity	Working Capacity (KN)	CP 114 Cap / CP 110 Cap
300x300	3,75	Unbraced	Base to 1st floor	2%	15	1,0	1 300	16,2	0,10h	960	1,35
400x400	7,60	Braced	$\alpha_{c1} = \alpha_{c2} = 1,0$	2%	15,2	1,0	2 310	15,2	0,17h	1 810	1,28
150x300 mullion	3,80	Braced	Fixed-Fixed	1%	19	0,87	475	19	0,26h	360	1,32
300x600	11,25	Braced	$\alpha_{c1} = \alpha_{c2} = 1,0$	2,5%	30	0,5	1 400	30	0,51h	1 200	1,17

Table based on South African Institute of Civil Engineers

Lecture Programme 1975

Course F - CP110

5.2.3 Changes Affecting Reinforcement Quantities

Significant changes have also been made to the following Code of Practice clauses which affect the amount of reinforcement provided in modern structures to satisfy statutory requirements.

- Minimum Percentage of Reinforcement. Generally more reinforcement is required for nominal design in columns and beams.

- Analysis Methods. The changes between earlier Elastic Design, Load Factor Design and Limit State Design all result in different amounts of bending and tension reinforcement for the same serviceability loading conditions and material properties.

- Use of Computer Technology. More advanced methods of analysis and detailing of reinforcement have show up deficiencies in past methods.

5.3 Partial Factors of Safety (PFOS)

The choice of PFOS in analysing existing structures should take into account the fact that it is possible to calculate the dead loads of the structure on the basis of actual measurements with an accuracy that would justify the reduction of the load factors. Other partial loading factors such as load combinations and sensitivity factor, and structural performance factor are not affected by the difference between a new design and existing structure and consequently should remain unchanged. This would also apply to the imposed load factors, particularly if the new imposed loading is substantially different from the past loading.

The following notation is used for PFOS

Gf = PFOS for Dead Loads

Gm = PFOS for Materials

If accurate dead loads are measured the recommended PFOS given in Ref [1] is to reduce Gf from 1.15 to 1.05.

The material factors m may also be reduced depending on whether concrete or steel tests have been carried out and Ref [1] suggests a reduction of Gm for concrete from 1.5 to 1.35 and Gm for steel reinforcement from 1.15 to 1.05.

Consequently, in the appraisal of existing structures it is possible to determine more accurate PFOS taking into account the known dead loads and material strengths.

5.4 Estimation of Residual Strength and Structural Evaluation

An essential aspect of the condition assessment of old structures is the determination of the design life and residual strength of the structure. This is dependent on the rate of deterioration of the materials of construction and the potential rate of corrosion of steel or reinforcement, which in turn is dependent on the maintenance history of the structure.

Several methods such as Ref [10] for predicting the residual service life of an RC structure have been proposed based on estimation of the rate of corrosion due to carbonation or chlorides and a flow diagram is shown on Fig. 5.2.

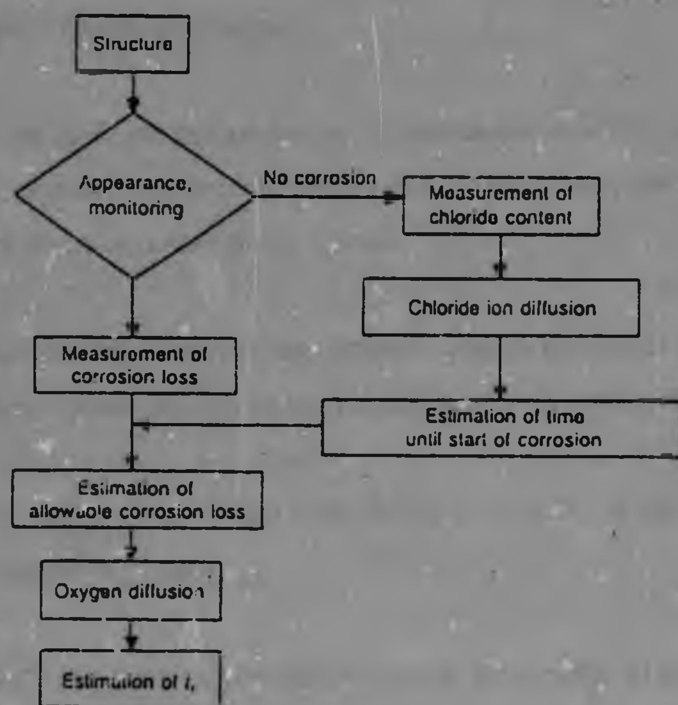


Fig 5.2 Diagram for Determination of Residual Service Life

5.4.1 Structural Evaluation

In the evaluation of an existing structure the residual service life prediction will determine the extent to which remedial action is undertaken. At a seminar on The Life of Structures, Ref [11], many topics dealt with the difficulties of accurately predicting the residual strength and the subject requires extensive further research.

Statistical reliability theory can be used to analyse designs when sufficient data is available on the existing materials of construction, the complexity of the structure and the loading history. The method using the Markov decision process, Ref [12], uses input data for transition probabilities, costs and relative importance to evaluate inprecise data.

5.5 Critical Factors in Design and Analysis

If continued or new use does not impose greater loads than are known to have been carried in the past without signs of overload, the structure can be deemed to be adequate, subject to its condition being sound and there are no obvious signs of distress.

If past loading is not known, reinforcement amounts and arrangements must be established in sufficient detail to allow calculations of load carrying capacity to be carried out.

Reinforcement details, shown on drawings, must always be checked on site by local opening-up in selected structurally significant places.

If the concrete strength has been ascertained by testing, permissible stresses or design strengths should be derived from the test results.

The effects of vibrations have a major influence on the structural condition of old structures and can lead to severe cracking especially in mining areas.

The information should now be studied and analysed. Checks should be made of the load carrying capacity of the structure and the margins of safety by calculation using the available information on actual loads and on the size and strength of the materials and components. In particular, the inherent stability and the adequacy of the construction should be considered.

5.6 Further Research in Structural Appraisal

5.6.1 Evaluation of the Effects in Structures resulting from Changes to Design Codes

The research is concerned with the effect on existing structures of the changes in design codes which have resulted in more reinforcement in certain sections. Does this mean that all old structures should be strengthened or are the actual factors of safety statistically acceptable?

5.6.2 An Integrated Structures Maintenance System

A systematic method of assessing the condition of structures, particularly bridges, would lead to research on preventative maintenance which could possibly obviate the main causes of deterioration in structures.

5.6.3 Determination of Level of Service in Structures

Research should be undertaken on the actual level of service in structures, which deals with the residual strength in existing structures and the actual factors of safety.

5.7 References

1. Fulton s Concrete Technology, Published by PCI, Midrand.
9. SAICE, **Lecture Programme 1975,** Course F - CP110
10. **Durability Design of Concrete Structures,** Magazine of Concrete Research, 1991, 43, No. 156.
11. The Institute of Structural Engineers, **The Life of Structures,** (April 1989) Seminar at Brighton.
12. M.A. Cesare et al, **Modeling Bridge Deterioration with Markov Chains,** Journal of Transportation Engineering Vol. 118 No. 6 (Dec 1992).

SECTION 6.0 : REPAIR TECHNOLOGY

6.1 Introduction

6.2 Principles of Repair Technology

6.3 Grouping of Concrete Repair Methods

6.4 Repair Techniques for Durability Problems in RC Structures

6.5 Repair Techniques for Structural Problems in RC Structures

6.6 Summary Tabulation of Repair Systems

6.7 Architectural Repair and Restoration

6.8 References

SECTION 6.0 : REPAIR TECHNOLOGY

6.1 Introduction

On completion of the diagnostic process and the identification and evaluation of the main causes of the observed problems a systematic approach should then be adopted for the repair technology.

The possible repair methods for reinforced concrete have been extensively documented in both trade literature and technical journals Ref. [13], [14], and consequently the objectives of this section is to relate the diagnostic process to remedial action in a systematic logical system that can be included in the proposed Expert System for the appraisal and repair of structures. This system should also be sufficiently flexible to incorporate new methods and technology which are constantly being developed and improved.

6.2 Principles of Repair Technology

The most important step in the design of repair or strengthening work is a careful assessment of the existing structure. The purpose of this assessment is to identify all defects and damage, to diagnose their causes and hence to assess the present and likely future adequacy of the structure. The information obtained from structural assessment can then be used to determine whether or not corrective work is required or is economically feasible when compared to the cost of demolition and replacement.

Depending on the maintenance history of the structure most structures tend to receive very little attention until major problems have been identified.

The history of the structure and the extent of alterations and previous repair work contribute to prolonging the service life of the structure and a typical pattern of the structures ability to perform satisfactorily is illustrated in Fig. 6.1

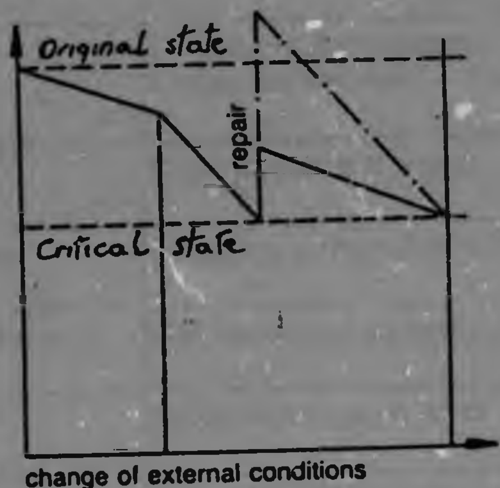


Fig 6.1 Typical Service Life History of structures

6.3 Grouping of Concrete Repair Methods

Repair technology is dependent on the diagnosis of the major cause of the problem identified by symptoms or test results. In order to specify appropriate repair methods for concrete the grouping has been categorised in the following Table 6.1 with references to extensive technical literature and market trade repair products.

Table 6.1 Application of Repair Systems

REPAIR SYSTEM GROUP	REFERENCE NOTES	REF.
Patch Repairs	Corrosion of Reinforcement Spalling and Carbonation of cover concrete	R1
Crack Injection	Repair of structural cracks	R2
Concrete Surface Repairs	Sealing and protection of surface	R3
Recasting Concrete Sections	Concrete and reinforcement deterioration	R4
Joint Repairs	Excess movements in joints	R5
Reinforcement Replacement	Inadequate strength and corrosion	R6
Finishes and Architectural Repairs	Age-related problems	R7
Structural Strenghening	Overall stability not adequate	R8
Concrete. Durability Cathodic Protection	Corrosion of reinforcement	R9

6.4 Repair Techniques for Durability Problems in RC Structures

In the case of sulphate attack or inadequate cover, it will usually be enough to provide adequate protection against future deterioration, provided that the cross-sectional area of the reinforcement has not been significantly reduced by corrosion, and that critical areas of concrete in compression have not been weakened. The same applies to chemical attack from stored or spilled substances.

Structures with severe Alkali-Aggregate Reaction can rarely be repaired with any lasting success. The structural effects are usually not serious and the reaction can sometimes be slowed down by drying out and protection against wetting. However, replacement of concrete is still considered the best long-term method.

In the case of chloride attack, it will usually be necessary to remove all chloride-contaminated concrete in contact with the reinforcement. This is because the chlorides act as catalysts in the corrosion process and are not consumed in the reaction.

6.5 Repair Techniques for Structural Problems in RC Structures

Where replacement of badly corroded reinforcement is not required, unsound concrete should be removed, the reinforcement should be cleaned of rust, for instance by grit blasting and new concrete or mortar cover provided and bonded to the clean concrete substrate. A bonding agent can be added to the repair material or, where adequate thickness is difficult to achieve, resin mortars may be used in place of cementitious materials.

There are usually difficulties in matching appearance of repairs with the original.

6.6 Summary Tabulation of Repair Systems

In order to tabulate the repair technology related to the primary cause of the problem the full extent of the problem has to be identified including the economic assessment. Obviously, there can be more than one cause creating the problem and the repair system cannot be comprehensively described in a summary tabulation. Data resulting from the appraisal of the old structure form the basis for the decision regarding repair systems shown on Table 6.2.

6.7 Architectural Repair and Restoration

Generally, specialist services are required for architectural renovation or restoration requiring the skills of artisans with experience in this work.

Table 6.2 Summary Tabulation of Repair Systems

PROBLEM IDENTIFICATION	SYMPTOMS OR TEST RESULTS	REPAIR SYSTEMS	REF
Concrete Materials:	Excess Chlorides	Cathodic Protection	R9
	Excess Sulphates	Reconstruction	R4
	Alkali-Aggregate Reaction	Surface Coating	R3
	Inadequate Cover	Patch Repair	R1
	Reinforcement Corrosion	Coating of Steel	R3
	Excess Carbonation	Cathodic, Protection	R9
	Surface Durability	Surface Coating	R3
	Waterproof and Damp Proof	Patch Repair	R1
Concrete Visible Defects:	Cracks	Crack Injection	R2
	Spalling	Patch Repair	R1
	Surface Finishes	Reconstruction	R7
Structural Defects:	Excess Deformations	Jacking, reconstruction	R8
	Structural Cracks	Crack Injection	R2
	Construction Eccentricities	Reconstruction	R7
Movement Problems:	Cracking at Joints	Joint Repair	R5
	Ground Subsidence	Underpinning	R8
Structural Steelwork:	Corrosion and Pitting		
	Excess Deformations		
Masonry:	Bulging, Spalling	Structural Strengthening	R8
Non-Structural Finishes:	Plaster Spalling, Crazing	Reconstruction	R7
	Mouldings Eroding	Cement-mortar replace	R7

6.8 References

13 Portland Cement Institute, **Diagnosing and Repairing the Surface of Reinforced Concrete Damaged by the Corrosion of Reinforcement.**

14 Durability Design and Repair of Concrete Structres, Magazine of Concrete Research, (Sept 1991).

SECTION 7.0 : AN EXPERT SYSTEM FOR STRUCTURAL APPRAISAL

SECTION 7.0 : AN EXPERT SYSTEM FOR STRUCTURAL APPRAISAL

7.1 Introduction to Expert Systems

Knowledge based expert system are computer programs that incorporate human expertise to provide advice on a wide range of topics. Expert systems are developed by creating a knowledge base collected from all possible sources, mainly with the help of an acknowledged expert in the domain.

The knowledge is extracted from human experts and the system attempts to emulate their methodology and performance. As with skilled humans, expert systems tend to focus on a narrow set of problems. Also, the knowledge is both theoretical and practical having been obtained through experience. Basic information on expert systems has been obtained from Ref [14].

Expert systems are perceived as a tool for decision analysis. Consequently, to better understand and appreciate expert systems, it is vital to understand its supporting elements, its evolution, and its role in the decision-making process. Further, the relationships, differences, and similarities among such topics as artificial intelligence, expert systems, heuristic programming, and decision support systems are very similar and extensive research in these systems has emerged from the United States over the past ten years. Artificial intelligence systems have been developed for such diverse subjects as chess playing and medical diagnosis in an attempt to match the performance of human experts.

Heuristic rules are rules that are developed through intuition, experience, and judgement. They do not represent knowledge of the interrelationships within a system but rather they represent guidelines through which a system may be operated. They evolve through years of experience and reside in the memory of an individual. Heuristics are often called rules of thumb.

The knowledge engineer is responsible not only for building the system, but also for the challenging and often complex process of knowledge acquisition. In this dissertation, research into age-related problems and personal experience in rehabilitation of structures have been the main source of knowledge acquisition.

The different methods of programming a knowledge-based system are summarised in Table 7.1 which identifies the principle difference in attributes of the programming methods.

Table 7.1 Comparison of Program Systems

ATTRIBUTE	ALGORITHMIC PROCEDURE	HEURISTIC PROGRAM	EXPERT SYSTEM
Subject Model	Quantitative	Quantitative or qualitative	Quantitative or qualitative
Logic System	Precise relationships	Imprecise relationships	Imprecise relationships
Internal Program System	Opaque and difficult to follow	Opaque	Transparent
Process	Structured development process	Unstructured development process	Relatively structured development process
Program Changes	Revision relatively difficult	Revision relatively difficult	Revision relatively easy
Variables	Numeric	Numeric or symbolic	Numeric or symbolic
Values	All values must be known to solve	All values usually must be known	Values may be known or unknown
Solution	Convergent by formulae	Satisfies by heuristics	Satisfies using statistics
Conclusions	Usually single (without explanation)	Usually single (without explanation)	Often multiple (with explanation)

7.1.1 Selection of an Expert System

Several different types of Expert System programs have been developed which are specifically suited for the different problem domains. The main differences are shown on Table 7.2

Table 7.2 Selection of an Expert System

RULE-BASED	MODEL-BASED	NEURAL NETWORK
Powerful heuristics	Requires design data	Learning and recall
Domain expert	Full fault coverage	Pattern recognition
Quick to start	Generates own rules	Learn by example
High complexity	Easy to extend	Fast Response

The choice of a Rule-based Expert System for the appraisal of structures has been made because of the ability to add to the knowledge-base and to extend the diagnostic decision logic with the acquisition of more advanced knowledge. The system used is EXSYSP, Ref [15].

7.1.2 Modules of a Typical Expert System

The building blocks of a typical expert system are diagrammatically shown in 7.1

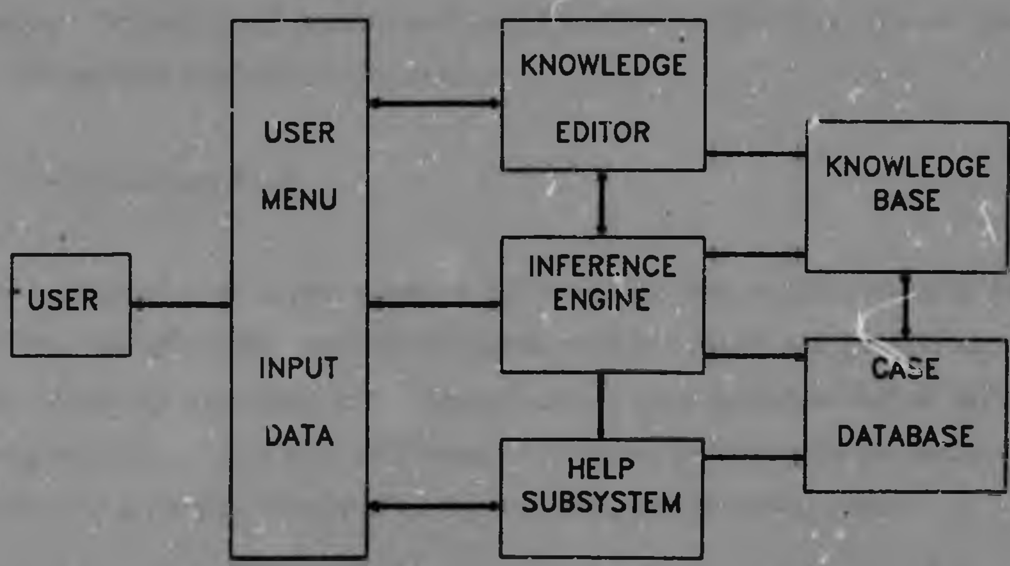


Fig 7.1 Typical Expert System

A typical expert system contains the project database, the knowledge base, the inference engine, the user interface and certain editing and explanatory subsystems. The function of each module is described in more detail below:

7.1.3 The Project Database

The project database holds information about the current state of the design. This includes all design parameters which define the structure such as member design and stresses which are used to check the adequacy of the member dimensions. Also included are the results of tests to check the properties of structural materials.

At each stage of the design process the project database is updated to form a basis for the following stages until it contains a complete model of the structure.

The linkages represent the software which allows the user to communicate with the system and which controls the processing. This will play a key role in making an integrated system viable.

The project database contains all relevant information gathered for the specific problem, intermediate conclusions, and confidence measures. The problem might refer to an existing structure investigated for the purpose of assessing such structure for repair, demolition or conversion. The database can be interfaced with external data acquisition systems.

7.1.4 The Knowledge Base

The major component of an expert system is the knowledge base, which consists of facts and heuristics. Facts are information that is widely shared, publicly available, and generally agreed upon by experts. Heuristics are private, little discussed rules of good judgement that an individual or group have gained through experience or the expert's innovative approach. The performance level of an expert system is primarily a function of the size and quality of its knowledge base.

The purpose of this database is to contain in concise form the vast amount of expert knowledge on all aspects relating to the appraisal, preservation, diagnosis and repair of structures.

The knowledge base can be interfaced with associated knowledge acquisition facilities, such as an external structural analysis program. In the structural appraisal system the knowledge base would contain all aspects relating to the appraisal, preservation and repair of structures.

In a rule-based system the knowledge base rules are usually in the form of IF ...... THEN ...... statements. The "IF" part, the premise, consists of a set of conditions. When the conditions are satisfied, the facts contained in the "THEN" part of the rule, the conclusion, are inferred. An example of a Knowledge Base rule is shown in Fig. 7.2.

KNOWLEDGE-BASE

RULE-BASED EXPERT SYSTEM

RULE-BASE

For identification of concrete defects

IF:

HIGH MOISTURE CONTENT (> 0.8)

AND:

Alkali-silica gel present

THEN:

PROBLEM IS A A R (probability 0.8)

ELSE:

TEST FOR CHLORIDE CONTENT

Fig. 7.2 Typical Knowledge-base Rule

7.1.5 The Inference Mechanism

As its name suggests, the inference mechanism compares the data in the project database with the information in the knowledge base and decides which information in the knowledge base is applicable to the data. This task is usually accomplished by pattern matching within the computer's memory.

Once the knowledge base has been established, the expert system utilises an inference process through which it ultimately arrives at its conclusion. The inference engine is activated during a consultation session which performs two primary tasks. First, it examines the status of the knowledge base and working memory so as to determine what facts are known at any given time, and to add any new facts that become available. Second, it provides for the control of the session by determining the order in which inferences are made. An alternative designation for the inference engine, and perhaps a more appropriate one, is that of knowledge processor. As the knowledge processing element of an expert system, the inference engine serves to merge facts with rules to develop new conclusions. The inference process is shown on Fig. 7.3.

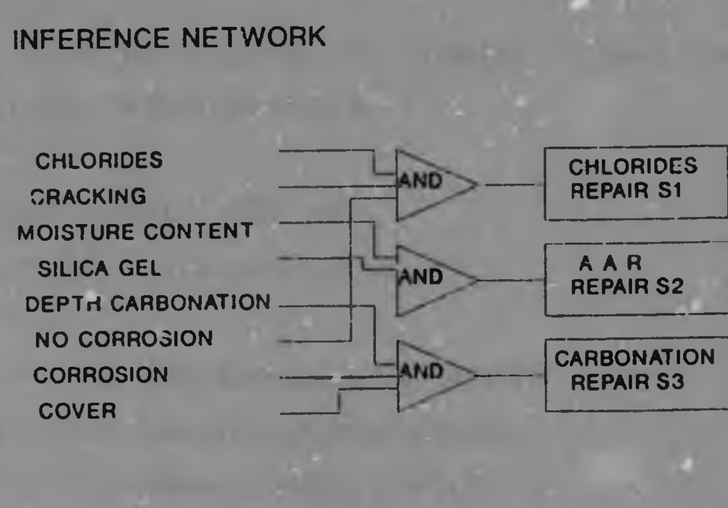


Fig. 7.3 Inference Network Logic Diagram

Using decision trees, inference proceeds along various linear pathways. The inference engine dynamically links (chains) rules together by matching a condition of one rule with a conclusion of another rule. Use is made of so-called forward and backward chaining. In forward chaining, the inference engine starts with facts and matches them to the condition of a rule. If the condition is satisfied, the conclusion is used to prove additional rules. This process continues until sufficient rules and facts are established to draw a final conclusion. In backward chaining, the inference engine attempts to verify the conclusions of a rule by determining if the conditions of the rule can be satisfied using other rules and facts.

The inference engine processes rules by examining first the conclusion of the rule and then its premises. Rules are selected that have conclusions which contribute to solving the set problem.

7.1.6 Uncertainty Methods

Three possible methods of dealing with uncertainty have been considered in applying an Expert System to the problem of structural appraisal and these methods are summarised as follows:

- Bayesion Probability

Bayes' formula may be used to determine the probability of a given conclusion (C) given certain evidence, or facts (f). The formula is given as:

$$p(C|f) = [p(f|C) \cdot p(C)] / p(f) \qquad (7.1)$$

where $$p(f) = p(f|C) \cdot p(C) + p(f|\sim C) \cdot p(\sim C) \qquad (7.2)$$

and $p(C|f)$ = probability of conclusion C given facts f

$p(f|C)$ = probability of facts f given conclusion C

$p(f)$ = unconditional probability of facts f

$p(C)$ = unconditional probability of conclusion C

$p(\sim C)$ = unconditional probability of *not* conclusion C

$p(f|\sim C)$ = probability of facts f given *not* C

- Fuzzy Sets

In conjunction with the fuzzy membership function, a set of rules for evaluating a conclusion using fuzzy logic has been provided. Specifically,

. If premises are connected by the logical AND operator, the minimum of the fuzzy values associated with the premises is used to determine the composite value for the premises.

. If premises are connected by the logical OR operator, the maximum of the fuzzy values associated with the premises is used to determine the composite value for the premises.

. If the fuzzy value of a premise is given as fv(i) then NOT fv(i) = 1 - fv(i).

- Exsys Method

The shell version of Exsys permits the use of three different methods for uncertainty. These are as follows. The members respresent confidence factors for conclusions only. Uncertainty in data input should be the subject of a separate external program.

- The 0 or 1 system
- The 0 to 10 system
- The -100 to 100 system

7.2 Structural Appraisal Expert System (SAES)

The development of this system has been based on the EXSYSP shell program which is a general purpose expert system allowing the Knowledge-base to be developed independently.

7.2.1 Objectives of the Expert System

- In simplest form the SAES will provide a procedure for guidance on the appraisal system and advice on obtaining more data.

- Systematic approach to testing and instrumentation.

- At more advanced levels an indication of the preservation rating of the structure.

- Diagnosis of primary causes of observed problems in structures.

- Predictions of the future life of the structure and recommended design factors.

- Advice on procedures for appraisal and renovation to inexperienced engineers.

- Provide a comprehensive record of the condition of an old structure in relationship to the history of the building and the structure.

7.2.2 Scope of the Structural Appraisal Expert System

The purpose of the SAES is to provide a logic system and a knowledge base to enable the end user to evaluate and recommend a procedure for the appraisal and refurbishment or preservation of historic structures.

The field of structural appraisal and renovation is very wide and the system described in this dissertation is restricted to old or historic structures of reinforced concrete and structural steel. Other structural materials such as timber or masonry could be included in the complete system but it is considered preferable that a prototype expert system should first be evaluated and tested before expanding the effort to include other materials.

The application of Expert Subsystems is an extension of this procedure and serves as a knowledge-base and guide.

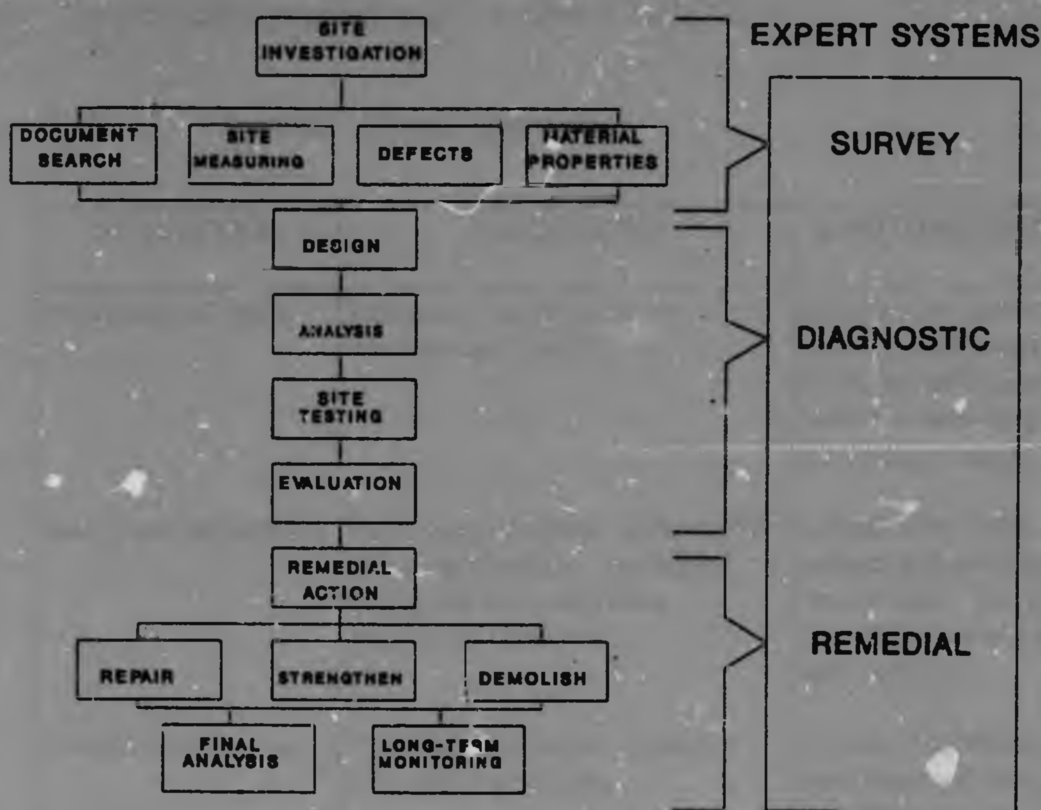


Fig. 7.4 Structural Appraisal Expert Systems

7.2.3 Principles of Blackboarding

In order for the Expert System to operate with several different Knowledge-bases with a common project database, the technique referred to as blackboarding has been utilised. This method allows a separation between the Expert Subsystems as shown on Fig. 7.4 so that the each Knowledge-base can be separately compiled and run independently but using variables from a common project database. The proposed Expert Subsystems are shown in Table 7.3.

Table 7.3 Summary of Expert Subsystems

SUBSYSTEM	OBJECTIVES	KNOWLEDGE-BASE
Preservation Criteria	Selection of old and historic structures for conservation.	Relationships between historic, architectural, structural and economic factors in determing preservation rating.
Survey and Inspections	Survey and inspection methods and recording of results. Specialised testing and instrumentation. Appraisal procedures.	Compilation of inspection systems and recording of observations. Choice of procedures, testing and instrumentation.
Forensic Engineering	Diagnostic evaluation of primary problems in structures.	Causes of deterioration. Symptoms and testing evaluation.
Remedial Technology	Information on repair technology.	Methods of repair and strengthening.

7.3 Diagnosis of Non-Structural Durability Problems in RC Structures

The use of an Expert System in the diagnosis of non-structural durability problems in reinforced concrete structures is considered as a subsystem within the general Structural Appraisal Expert System. The Knowledge base for this expert subsystem has been comprehensively described in Chapter 4.5.

7.3.1 Development of the Rule-base

The final stages in the development of this system is the Knowledge-base which has been determined from the Decision Network. A typical sector of the rule-base attribute-value relationships and confidence factors has been developed for diagnosis of problems in concrete.

The Knowledge-base rules have been developed in three stages:

- Comprehensive data and test results are available and a quick diagnosis is possible. The rules based on backward chaining are simple and contain the sequence of linkages corresponding to the HIGH risk significance given in Table 4.3 and shown diagrammatically as H in Fig 4.2. An example of these rules are given in Annexure A, Rules 1-4.

- Reasonable range of data is available but no clear diagnosis is possible due to insufficient test results, conflicting data or imprecise data. In this analysis the rule base will reach a series of possible conclusions with different confidence factors. An external program, written in BASIC is then activated and this program will then determine a new set of relative confidence factors in accordance with the method of calculation given in section 7.4.

- Incomplete test results are available. In general an extensive data-base is needed to successfully diagnose an observed problem in RC structures. However, the Knowledge-base rules can be written to assess the data available and recommend further information required, and guidance on the procedure to be followed.

7.3.2 Derivation of the Rules

In accordance with the terminology used in the EXSYS-PRO program the first step is to define the CHOICES (or conclusions) which correspond to the results of the analysis.

CHOICES ARE:
- EXCESS CHLORIDES
- EXCESS CARBONATION
- ALKALI-AGGREGATE REACTION
- INADEQUATE COVER
- INSUFFICIENT DATA
- CALL EXTERNAL PROGRAM

The test data has to be defined as VARIABLES and this has been done in accordance with the notation system in section 4.5.5. The VARIABLES can be descriptive or numeric.

The rules are then compiled in terms of the QUALIFIERS which are the conditional clauses relating the VARIABLES to the range of test data as given in Table 4.2 as in the following examples:

RULE NO.	QUALIFIER	VARIABLES	DATA RANGE
7	Exposure Conditions	Fm	Very Wet or Normal
	Crack Pattern	Fc	Type of Cracking : MAP
	Cover Depth	Fo	< 10 mm
	Depth Free of Carbonation	Fd	< 15 mm and > 5 mm

The relationship between the QUALIFIERS and the CONCLUSIONS is determined by Logic Decision Diagram as shown in Fig 4.2. In the above example of RULE No. 7 if the QUALIFIERS are satisfied the CONCLUSION or CHOICE is that the identified problem is ALKALI-AGGREGATE REACTION with a probability or confidence factor of 7/10.

The complete rule is then listed in Appendix A as Rule No. 7.

The development of the complete set of rules is compiled by considering all the possible logic combinations of VARIABLES (11 specified in Section 4.5.5) with the range of data given in Table 4.2 (3 groups of 9 data elements) and the CHOICES or CONCLUSIONS defined previously.

Obviously, the total number of rules can be very large taking into account all combinations. Consequently, a probability or confidence factor has been introduced to limit the number of rules which can reach meaningful conclusions.

Finally, the validity of the Knowledge-base rules is totally dependent on the data-base of information which relates the symptoms to the underlying problem. In most actual case studies there is no quick or obvious diagnosis and some form of statistical analysis is required.

The proposed expert system rule base offers an opportunity to give guidance and reach a most likely conclusion where the data is incomplete or inconclusive.

7.3.3 External Programs

An essential facility in this Expert System is the option to call external programs at different stages of the running of a consultative session. External programs which could be accessed by the SAES include the following separate systems.

- Project Database. This would include all information on the physical structure, results of inspections and tests and the structural details.

- Evaluation of Data. Much of the data on old structures is uncertain and a statistical method such as Markov Chains could provide confidence limits for data.

- Structural Analysis. In order to check the actual level of stresses in the structure an analysis program could provide data on the overall stability and design of structural elements.

- Blackboarding Procedures. This program would control the procedures in the separate expert subsystems.

- Residual Life of Structure. Based on test results a prediction of the degree of deterioration and the residual service life of the structure can be made.

7.4 Application to Case Study

For validation this diagnostic system has been applied to an existing structure where test data has been obtained and the diagnostic Expert System used to determine the primary causes of steel corrosion and deterioration of the concrete. The details of this case study are given in Tables 7.4 and 7.5.

Table 7.4 Case Study for Three R.C. Elements of the Structure

LABORATORY ANALYSIS RESULTS				
		R.C. COLUMN	R.C. BEAM	R.C. SLAB
Exposure conditions	Fm	Exposed Industrial atmosphere	Exposed to Indus-trial atmoshphere	Internal slab, water leakage
Surface texture	Fs	Crack repairs visible	Exposed aggregate	Alkali silica gel present
Crack pattern	Fc	Large cracks spalling	Vertical hairline cracks	Extensive map cracking
Crack width	Fw	0.7 - 1.5 mm	0.1 - 0.3 mm	0.5 - 0.8 mm
Cover meter reading	Fo	Ave 21.3 mm	Ave 8.2 mm	Ave 14.8 mm
pH value of cover	Fp	7.8	12.8	9.3
Chloride content	Fh	0.26%	0.48%	0.15%
Alkali content	Fa	3.7 kg/m^3	2.4 kg/m^3	7.6 kg/m^3
Expansion of core samples	Fx	0.52 mm/m	0.43 mm/m	0.72 mm/m
Carbonation. Measured depth by testing	FD	30 - 35 mm	Ave 5.6 mm	Ave 11.8 mm

Analysis of Actual Test Results

Based on the laboratory analysis results shown in Table 7.4 a factor representing these results has been determined by comparison with the range of data given in Table 4.2 which is grouped according to the risk of corrosion to reinforcement. This factor representing actual test results is shown as the bottom number in each line in Table 7.5.

The calculation of these factors in Table 7.5 is as follows for the diagnosis of EXCESS CHLORIDES for the RC Beam.

Table 7.4.1 Factor Representing Test Results for RC Beam

SYMPTOM	TEST RESULT	TABLE 4.2 DATA RANGE	RF	EQUIVALENT TEST RESULT FACTOR
Fm	Exposed Industrial Atmosphere	Only relative humidity values given	7-8	7
Fc	Vertical Hairline Cracks	Fine Cracks	4-9	7
Fo	Ave 8.2 mm	< 10 mm	8	8
Fd	Fo - FD = Ave 2.6 mm	< 5 mm	7-8	7
Fw	Ave 0.2 mm	0.1 - 0.3 mm	5-8	5
Fp	12.8	> 12.0	1-2	2
Fh	0.48%	0.2% - 0.6%	5-8	7
Fa	2.4 Kg/m³	1.8 - 3.8 Kg/m³	4-9	6
Fx	0.43 mm/m	0.4 - 0.8 mm/m	9-5	5

Table 7.5 Typical Results of Diagnosis for R.C. Beam

DIAGNOSIS	SYMPTOMS or TESTS RESULTS FOR R.C. BEAM								CONFIDENCE FACTOR
	Fm	Fc	Fo	Fd	Fw	Fp	Fh	Fa	Fx	
EXCESS CHLORIDES	3 7	2 7	4 8	2 7	2 5	4 2	5 7	2 6	1 5	77%
EXCESS CARBONATION	3 7	3 7	4 8	5 7	2 5	4 2	1 7	2 6	1 5	72%
INADEQUATE COVER	4 7	4 7	5 8	1 7	3 5	4 2	2 7	2 6	1 5	73%
AAR	5 7	4 5	2 8	1 7	2 5	3 2	1 7	4 6	5 5	60%

(Top Number = Factor representing weighting significance. This is the same Weighting Factor that was shown in Table 4.3)

(Bottom Number = Factor representing actual test results)

(Confidence Factor calculated using Fuzzy Set methods)

The objective of calculating a CONFIDENCE FACTOR is to obtain a comparative value for the most critical of the symptoms or test results. With reference to Table 4.3, only the H or M Risk Significance Factors are considered relevant and the data corresponding to these groups is then combined with the Weighting Factor which is the same in Tables 4.3 and 7.5. The resulting calculation is then compared with the maximum total calculated from Table 4.3 as the sum of the highest Risk Factors multiplied by the Weighting Factor.

Based on Table 4.3 this calculation is evaluated as follows for the diagnosis of EXCESS CHLORIDES:

Critical Test Result	**Fm**	**Fo**	**Fp**	**Fh**
Weighting Factors	3	4	4	5
Max. Risk Factor	5	8	8	9

Max. Total for Confidence Factor calculation = (3x5) + (4x8) + (4x8) + (5x9) = 124

Using the actual data and the Equivalent Test Result Factor from Table 7.4.1 the calculation of the Confidence Factor for EXCESS CHLORIDES is then determined as follows:

Critical Test Result	**Fm**	**Fo**	**Fp**	**Fh**
Weighting Factors	3	4	4	5
Max. Risk Factor	7	8	2	7

Confidence Factor = [(3x7) + (4x8) + (4x2) + (5x7)] / 124

= 77% as shown on Table 7.5

In conclusion the Confidence Factors calculated in Table 7.5 indicate that EXCESS CHLORIDES is the primary cause of the problem as deduced from the symptoms and test results.

Similarly, the Confidence Factors for the RC Column and the RC Slab have been calculated in Tables 7.5.1 and 7.5.2 respectively which follow:

Table 7.5.1 Typical Results of Diagnosis for RC Column

DIAGNOSIS	SYMPTOMS or TESTS RESULTS FOR R.C. COLUMN									CONFIDENCE FACTOR
	Fm	Fc	Fo	Fd	Fv	Fp	Fh	Fa	Fx	
EXCESS CHLORIDES	3 7	2 7	4 4	2 9	2 8	4 8	5 5	2 8	1 7	76%
EXCESS CARBONATION	3 7	3 7	4 4	5 9	2 8	4 8	1 5	2 8	1 7	85%
INADEQUATE COVER	4 7	4 6	5 4	1 9	3 8	4 8	2 5	2 8	1 7	79%
AAR	5 7	4 5	2 4	1 9	2 8	3 8	1 5	4 7	5 7	78%

In the case of the reinforced concrete column the highest confidence factor indicates that the major cause of the observed cracking and corrosion is due to excess carbonation which has extended beyond the depth of the cover concrete to the reinforcement.

Table 7.5.2 Typical Results of Diagnosis for RC Slab

DIAGNOSIS	SYMPTOMS or TESTS RESULTS FOR R.C. SLAB									CONFIDENCE FACTOR
	Fm	Fc	Fo	Fd	Fw	Fp	Fh	Fa	Fx	
EXCESS CHLORIDES	3 7	2 7	4 6	2 7	2 7	4 7	5 2	2 9	1 8	67%
EXCESS CARBONATION	3 7	3 7	4 6	5 7	2 7	4 7	1 2	2 9	1 8	81%
INADEQUATE COVER	4 7	4 7	5 6	1 7	3 7	4 7	2 2	2 9	1 8	83%
AAR	5 7	4 9	2 6	1 7	2 7	3 7	1 2	4 9	5 8	92%

The above analysis indicates that the most likely cause of the observed problems is alkali-aggregate reaction which is confirmed by the test results.

7.5 Further Applications of Exsys Shell Program

Three possible applications of the Structural Appraisal Expert System using the Exsys Shell Programme are summarised in the following Table 7.6. Each system would normally be run independently but use the same project database by means of the Blackboarding technique.

Table 7.6 Further Applications using EXSYS

EXPERT SYSTEM	OBJECTIVES OF SYSTEM
Preservation Rating	Determination of the relative merits of Historic Importance, Structural Appraisal Results and Economic Feasibility Factors.
Forensic Engineering	Essentially concerned with symptoms, evaluation of test data, diagnosis and identification of durability problems, repair and remedial work for each structural material of construction.
Prediction of Life-span	The future life-span of the structure must be assessed after the structural appraisal and remedial work has been completed

7.6 Conclusion

An Expert System for the structural appraisal of old or historic R.C. structures has been introduced in this dissertation. The system has been applied to typical elements of an existing structure and this case study has reached the same conclusion as the concrete technology expert. Further details of the case study have been includd in Appendix D.

7.7 References

8. Fulton's Concrete Technology - Published by P.C.I. Midrand - South Africa
14. James P Ignizio., Introduction to Expert Systems - Published McGraw-Hill
15. Professional EXSYS Software Package

SECTION 8.0 : TESTING AND INSTRUMENTATION

Looking at it practically

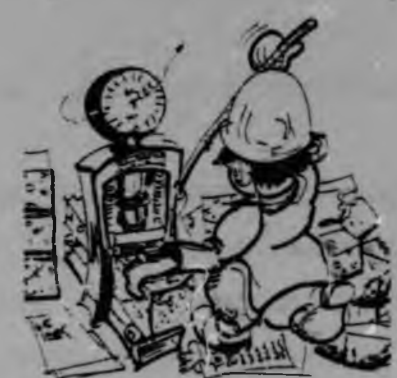
– TESTING

by **John G Richardson**

There appears to be no end to the tests we are requi: d to apply to concrete in its various states…

We may have to 'slump it'…

'flow test' it,

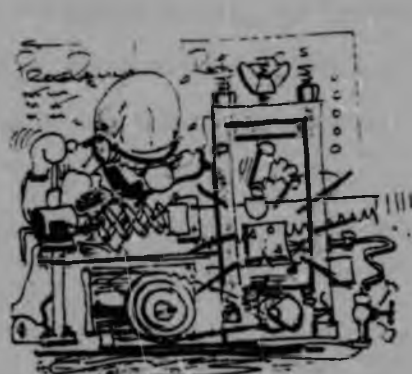


break it, in a variety of interesting ways.

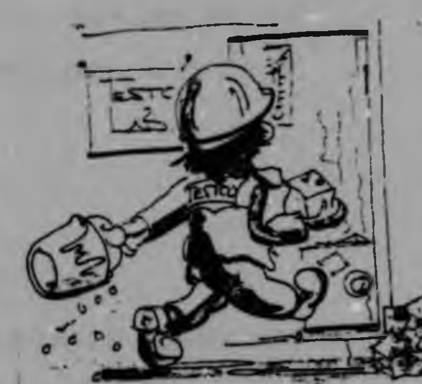
On site we may be called upon to buzz things through it..

'figg' it…

Bounce things off it, and generally mistreat it!



It's a salutary thought, however, that altho :gh we put a lot of store by the results… and whatever the boffins come up with next.



as well as the sampling procedures, what we mostly test is… the specimen producer/selecter, the tester and the test equipment!

SECTION 8.0 : TESTING AND INSTRUMENTATION

8.1 Introduction to Testing of Structures

Although extensive literature and documentation is available on this subject, the purpose of including testing and instrumentation in this dissertation is to relate the diagnostic process to significant testing procedures and to provide a comprehensive schedule of the latest instrumentation available. A critical review of the need for testing has been noted previously and an evaluation of suitable instruments and testing methods is included in a summary tabulation.

There is currently considerable research being undertaken on new non-destructive testing methods although the interpretation of results and the reliability of instruments is not always known, and all testing procedures should be complemented with experienced judgement.

8.2 Specialised Instrumentation

The use of specialised instrumentation has become very advanced in recent years. Accurate condition assessment instruments and hi-tech non-destructive testing are important means of identifying the condition of existing structures and in diagnosing the residual strength before undertaking remedial action.

In order to facilitate an understanding of the wide range of instruments and testing methods currently available the type of instrument suitable for specific investigation has been summarised and grouped according to Table 8.1. In addition, a comprehensive schedule of instruments with a brief specification and source of availability has been included as Appendix C.

The study of instrumentation has been considered from two points of view.

- Firstly, an analysis and grouping of the various structural properties of materials and diagnostics tests which can be carried out using both destructive and non-destructive methods.

SECTION 8.0 : TESTING AND INSTRUMENTATION

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- Firstly, an analysis and grouping of the various structural properties of materials and diagnostics tests which can be carried out using both destructive and non-destructive methods.

- Secondly, an analysis and grouping of the type of instruments currently available and the basic principles of the instrument. The reliability and accuracy of instruments is a specialised subject in its own right and requires extensive laboratory testing and research in order to ascertain the limitations and accuracy of the instrument.

8.3 Structural Instrumentation Testing

The purpose of testing with specialised instrumentation is to confirm the diagnosis or condition of the structure which has been inspected and appraised by experienced engineers. Instrumentation testing is very expensive and the results are often inconclusive and not very accurate. consequently, before instrumentation testing is undertaken the purpose of the testing should be evaluated so that the results can be reliably interpretated and the costs of the testing should not exceed reasonable remedial costs.

8.4 Long-term Monitoring and Management Systems

The importance of long-term monitoring is dependent on the extent to which an old or historic structure is deteriorating and the knowledge of the primary causes of the problem. Also if remedial work has taken place it may be necessary to monitor the effects of readjustment of stresses in the structure over a period of time.

Management systems for inspection and evaluation of bridge structures have been recognised as an essential economic maintenance factor which can prolong the service life of the structure. However, similar systems for historic buildings have not been implemented and considerable extra data would be needed to effectively use a management system.

Table 8.1 Summary of Structural Testing Instrumentation

TESTING SUBJECT	STRUCTURAL CHARACTERISTIC	INSTRUMENT	SYSTEM OF MEASUREMENT	REF
CONCRETE	Strength Test	Schmidt Hammer	Impact rebound	C1
		Lak-Test		C9
		Core Drilling	Core sampling and lab testing	C2
	Resistivity	Resistivity Meter	Electronic circuitry	C3
	Surface Durability	Autoclaim	Air and water peermeability and water absorbsion	C8
	Position and size of reinforcing steel	Mini probe for covermeter	Fitted to covermeter	C4
	Corrosion in concrete	4-point Werner Method		C5
	Assessing chlorides in concrete	Hach Test	Chemical testing	C6
	Covermeters	CM5	Audio detection by Sonk Waves	C7
		Kolectric MicroCovermeter		C7a
		Profometer 3		C7b

Table 8.1 (Cont.)

TESTING SUBJECT	STRUCTURAL CHARACTERISTIC	INSTRUMENT	SYSTEM OF MEASUREMENT	REF
STRUCTURAL STEEL	Chemistry of metal	S Sam 2 (material sample remover)	Removes samples for metallurgical analysis	S1
	Surface flaws Surface corrosion Mech Propos	Flaw detector surface sampler		S5
	Localised corrosion	STRET (corrosion microscope)	Measures variations in electrical potential	S2
	Coating thickness	Deltascope MP3 Isoscope MP3	Measures coating thickness	S3 S3a
	Section thickness corrosion	Cygnus 2	Ultrasonic thickness gauge for corrosion checks	S4

Table 8.1 (Cont.)

TESTING SUBJECT	STRUCTURAL CHARACTERISTIC	INSTRUMENT	SYSTEM OF MEASUREMENT	REF
COMPLETE STRUCTURE	FORCES	Load Cells	Measures pressure in load cell or changes to electrical resistance	T1
DIMENSIONS	Linear Measurements	Solex Digitape Suparule	Measures reflected beam signals	T2 T2a
STRAIN	Movement in structures	Range of markers and targets	Provides reliable monitoring points	T3
	Angle deformations	V30 Angle Indicator	Angle and vertical alignment	T4
	Deformation meter	R3413 Proceq	Measures settlement and shrinkage	T5
	Profiling distorted structures or walls	Giraffe	Measures wall profiles	T6
	Displacement sensors	Performance Instrumentation		T7
	Crack monitoring	Avonguard		T8
TEMPERATURE		PMSZ		T9

Table 8.1 (Cont.)

TESTING SUBJECT	STRUCTURAL CHARACTERISTIC	INSTRUMENT	SYSTEM OF MEASUREMENT	REF
BRICKWORK AND MASONRY	Flexural Strength of Mortar	Brench	Digital Torque gauge	B1
	Mortar Joint	Schmidt Hammer Model P	Impact Hammer	B2
	Brick Strength	Compression test	Compressive strength of bricks	
	Internal Inspection	Borescopes Econoscope		

Table 8.1 (Cont.)

TESTING SUBJECT	STRUCTURAL CHARACTERISTIC	INSTRUMENT	SYSTEM OF MEASUREMENT	REF
SPECIALS	Voids in Structures	Econoscope	Light scope for internal viewing of cavities in walls or concrete	M1 M4
				M10
	Loadcells			
	Adhesives testing	Laboratory	X-Ray equipment. Extensometers	M2
	Pipes and hydraulics	UVS 1608		M9
	Vibrations in structures		Measures vibrations and shock waves	M3
	Temperature			M11
	Screed soundness	BRE Screed Tester		M5
	Accuracy of covermeter	Computer test programme	Tests CM5 covermeter	M6
	Dampness kit			M12
	Investigation kit	Lab equip for CMC and asphalt	(DRAINARD KILMAN)	M7
		Addleson kit		M8

Table 8.1 (Cont.)

TESTING SUBJECT	STRUCTURAL CHARACTERISTIC	INSTRUMENT	SYSTEM OF MEASUREMENT	REF
PILES	Cross-section continuity	Electro-dynamic shaker	Dynamic response measurements	P1
	Accoustic testing	Howell M1	Transducers measure impulses	P2
	Pile integrity		Sonic integrity testing	P3
SURVEY	Distance measures	Wheel ultrasonic		P4
	Movement monitory			R3

8.5 References

16. Non-destructive Testing for Reinforcement Corrosion. CONCRETE. Jan/Feb 1993.

17. Structural Testing [1] to [3]. THE STRUCTURAL ENGINEER. Vol. 67 No. 2/24 January 1989.

18. Paul Phillips. Structural Repair Partnership. London. INTEGRATED INSTRUMENTATION SYSTEMS IN THE TESTING OF SUSPECTED STRUCTURAL WEAKNESS.

19. The Life of Structures - The Role of Physical Testing. JOINT I.STRUC.E./B.R.E. INTERNATIONAL SEMINAR April 1989. Brighton.

20. Methods of Testing Concrete. BRITISH STANDARDS INSTITUTE. 1881.

SECTION 9.0 : CONCLUSIONS

9.1 Review of the Objectives of this Dissertation

9.2 Further Research

9.3 Towards a Code of Practice for Appraisal and Renovation

SECTION 9.0 : CONCLUSIONS

9.1 Review of the Objectives of this Dissertation

In review of the procedures and flow charts which been prepared for the appraisal of structures, several factors have emerged in the case studies which confirm that a simple, straight assessment is difficult to inspect and often covered by finishes or brickwork. Secondly, very little experience in testing and sampling is currently available. The procedures followed very in accordance with the flow chart suggested in this dissertation.

The establishment of diagnostic knowledge base on durability problems in RC structures has been validated by comparing the conclusions in the Case Study with the opinions of a concrete technology expert in arriving at the same conclusions.

Development of the Structural Appraisal Expert System has been simple to initiate and establish a rule-base for data which leads to reasonably quick conclusions. However, when information is uncertain or inadequate the system logic cannot reach satisfactory conclusions. Also the concept of accessing external programs has been tested and requires an extensive knowledge of computer software systems before working. It is considered that a shell program such as EXSYS is probably not the best way of using computers for the problems of diagnosis and appraisal of structures.

9.2 Further Research

Appraisal and conservation of structures is a relatively new field of research in civil engineering and will offer many subjects for further research.

- Determine the service life of a structure is dependent on establishing the rate of deterioration and a detailed knowledge of the history and state of stress of the structure. Choice of partial factors of safety in design is also critical and requires research.

- The diagnosis of primary causes of observed problems is dependent on adequate inspection and test data and the statistical limitations and uncertainty methods need to evaluated by further research.

- The use of more sophisticated programs which can undertake pattern matching of defects in structures could help in forensic engineering.

- The economics of renovation of structures is still very much an ill-defined subject and research in defining the key interia and evaluating a proposal would have significant benefits.

9.3 Towards a Code of Practice for Appraisal and Renovation

As more structures are considered for conservation the need will arise for a common engineering approach to avoid the pitfalls of inexperience and having to reinvent the wheel each time. A committee should eventually be formed to prepare a document with procedures as defined in this dissertation.

APPENDIX A : PRINTOUT OF DIAGNOSTIC RULE-BASE PROGRAM

Subject:
STRUCTURAL APPRAISAL EXPERT SYSTEM

Author:
R. S. FINKELSTEIN

Starting text:
MENU DRIVEN OPERATION

Ending text:
END OF TEST DATA

Uses all applicable rules in data derivations.

Probability System: 0 - 10

DISPLAY THRESHOLD: 1

QUALIFIERS:

1 EXPOSURE CONDITIONS ARE

VERY DAMP
NORMAL
DRY

Name: EXPOSURE

2 CRACK PATTERN IS

HAIRLINE CRACKS
SPALLING
MAP-CRACKING
BURSTING

Name: CRACK PATTERN

3 SURFACE TEXTURE IS

CRACKS VISIBLE
EXPOSED AGGREGATE
ALKALI SILICA GEL PRESENT
RUST STAINED

Name: SURFACE TEXTURE

CHOICES:

1 THE IDENTIFIED PROBLEM IS EXCESS CHLORIDES

2 THE IDENTIFIED PROBLEM IS EXCESS CARBONATION

3 THE IDENTIFIED PROBLEM IS ALKALI-AGGREGATE REACTION

4 THE IDENTIFIED PROBLEM IS INADEQUATE COVER

5 INSUFFICIENT DATA TO IDENTIFY THE PROBLEM

6 CALL EXTRNAL PROGRAM FOR STATISTICAL EVALUATION

FORMULAS:

1 [FH] > 0.6

2 [FP] < 3

3 [FD] < 3

4 [FP] < 8

5 [FD] < 5

6 [FA] > 3.8

7 [FX] > 0.08

8 [FD] < 10

9 15 > [FD] > 5

10 [FD] > 5

11 [FD] < 15

12 [FH] > 0.6

13 [FP] < 8

14 [FD] < 5

15 [FP] < 8

16 [FO] < 10

17 [FD] > 5

18 [FD] < 15

19 [FO] > 10

20 [FO] < 25

21 [FH] < 8

22 [FP] < 8

23 [FA] < 2

24 [FX] < .06

25 [FD] < 5

26 [FH] < 0.4

27 [FO] < 20

28 [FH] < 13

29 [FH] > 0.2

30 [FA] < 3

31 [FX] < 0.5

32 [FD] > 5

33 [FO] < 15

34 [FP] < 10

35 [FH] < 0.2

36 [FA] > 3.8

37 [FX] > .07

VARIABLES:

1 FH

CHLORIDE CONTENT (% cement mass)

Numeric variable

2 FP

pH VALUE OF COVER CONCRETE

Numeric variable

3 FD

FREE CARBONATION DEPTH

Numeric variable

4 FO

DEPTH OF COVER (mm)

Numeric variable

5 FA

ALKALI CONTENT (kg/m3)

Numeric variable

6 FX

FREE EXPANSION STRAIN

Numeric variable

```
RULES:

------------------------------------------

RULE NUMBER: 1    (CHLORIDES(90%))
IF:
       EXPOSURE CONDITIONS ARE VERY DAMP
  and  [FH] > 0.6
  and  [FP] < 8

THEN:
       THE IDENTIFIED PROBLEM IS EXCESS CHLORIDES - Confidence=9/10

------------------------------------------

RULE NUMBER: 2    (CARBONATION(90%))
IF:
       EXPOSURE CONDITIONS ARE VERY DAMP
  and  [FD] < 5
  and  [FP] < 8
  and  [FO] < 5

THEN:
       THE IDENTIFIED PROBLEM IS EXCESS CARBCNATION - Confidence=9/10

------------------------------------------

RULE NUMBER: 3    (ALKALI(90%))
IF:
       EXPOSURE CONDITIONS ARE VERY DAMP
  and  CRACK PATTERN IS MAP CRACKING
  and  [FA] > 3.8
  and  [FX] > 0.08

THEN:
       THE IDENTIFIED PROBLEM IS ALKALI-AGGREGATE REACTION - Confidence=9/10

------------------------------------------

RULE NUMBER: 4    (INADEQUATE COVER)
IF:
       EXPOSURE CONDITIONS ARE VERY DAMP
  and  CRACK PATTERN IS HAIRLINE CRACKS OR SPALLING
  and  [FO] < 10
  and  [FD] > 5
  and  [FD] < 15

THEN:
       THE IDENTIFIED PROBLEM IS INADEQUATE COVER - Confidence=9/10

ELSE:
       INSUFFICIENT DATA TO IDENTIFY THE PROBLEM - Confidence=5/10

------------------------------------------

RULE NUMBER: 5    (CHLORIDES(60%))
IF:
       EXPOSURE CONDITIONS ARE NORMAL
  and  [FH] > 0.6
```

```
  and  [FP] < 8

THEN:
       THE IDENTIFIED PROBLEM IS EXCESS CHLORIDES - Confidence=6/10


----------------------------------------

RULE NUMBER: 6   (CARBONATION(60%))
IF:
       EXPOSURE CONDITIONS ARE NORMAL
  and  [FD] < 5
  and  [FP] < 8

THEN:
       THE IDENTIFIED PROBLEM IS EXCESS CARBONATION - Confidence=6/10


----------------------------------------

RULE NUMBER: 7   (ALKALI(70%))
IF:
       EXPOSURE CONDITIONS ARE NORMAL
  and  CRACK PATTERN IS MAP CRACKING
  and  [FO] < 10
  and  [FD] > 5
  and  [FD] < 15

THEN:
       THE IDENTIFIED PROBLEM IS ALKALI-AGGREGATE REACTION - Confidence=7/10


----------------------------------------

RULE NUMBER: 8   (CARBONATION(80%))
IF:
       EXPOSURE CONDITIONS ARE NORMAL
  and  SURFACE TEXTURE IS CRACKS VISIBLE
  and  CRACK PATTERN IS HAIRLINE CRACKS OR SPALLING
  and  [FO] > 10
  and  [FO] < 25
  and  [FH] < 0.4
  and  [FP] < 8
  and  [FA] < 2
  and  [FX] < .06
  and  [FD] < 5

THEN:
       THE IDENTIFIED PROBLEM IS EXCESS CARBONATION - Confidence=8/10


----------------------------------------

RULE NUMBER: 9   (CHLORIDES(70%))
IF:
       EXPOSURE CONDITIONS ARE NORMAL
  and  SURFACE TEXTURE IS EXPOSED AGGREGATE
  and  CRACK PATTERN IS HAIRLINE CRACKS OR SPALLING
  and  [FO] < 20
  and  [FH] < 13
  and  [FH] > 0.2
  and  [FA] < 3
  and  [FX] < 0.5
  and  [FD] > 5
```

THEN:

THE IDENTIFIED PROBLEM IS EXCESS CHLORIDES - Confidence=7/10

RULE NUMBER: 10 (ALKALI(80%))

IF:

EXPOSURE CONDITIONS ARE VERY DAMP
and SURFACE TEXTURE IS ALKALI SILICA GEL PRESENT
and CRACK PATTERN IS MAP CRACKING
and [FO] < 15
and [FP] < 10
and [FH] < 0.2
and [FA] > 3.8
and [FX] > .07

THEN:

THE IDENTIFIED PROBLEM IS ALKALI-AGGREGATE REACTION - Confidence=8/10

EXSYS Pro ** CHANGE INPUT DATA **

R.C. COLUMN

1 EXPOSURE CONDITIONS ARE NORMAL
2 CRACK PATTERN IS SPALLING
3 SURFACE TEXTURE IS CRACKS VISIBLE
4 CHLORIDE CONTENT (% cement mass) = .26
5 pH VALUE OF COVER CONCRETE = 7.8
6 FREE CARBONATION DEPTH = -9
7 DEPTH OF COVER (mm) = 21.3
8 ALKALI CONTENT (kg/m3) = 3.7

Enter number of line to change <O> for original data <R> to run the data
<H> for help Memo <F10>

EXSYS Pro ** RESULTS **

		VALUE
1	THE IDENTIFIED PROBLEM IS EXCESS CARBONATION	6
2	INSUFFICIENT DATA TO IDENTIFY THE PROBLEM	5

All choices <A> only if >1 <G> Print <P> Change/rerun <C>
Rules used <line #> Quit/save <Q> Help <H> Memo <F10> Done <D>

EXSYS Pro ** CHANGE INPUT DATA **

R.C. BEAM

1 EXPOSURE CONDITIONS ARE NORMAL
2 CRACK PATTERN IS HAIRLINE CRACKS
3 SURFACE TEXTURE IS EXPOSED AGGREGATE
4 CHLORIDE CONTENT (% cement mass) = .48
5 pH VALUE OF COVER CONCRETE = 12.8
6 FREE CARBONATION DEPTH = 6
7 DEPTH OF COVER (mm) = 8.2
8 ALKALI CONTENT (kg/m3) = 2.4
9 FREE EXPANSION STRAIN = .043

Enter number of line to change <O> for original data <R> to run the data
<H> for help Memo <F10>

EXSYS Pro ** RESULTS **

		VALUE	PREV.
1	THE IDENTIFIED PROBLEM IS EXCESS CHLORIDES	7	NONE
2	INSUFFICIENT DATA TO IDENTIFY THE PROBLEM	5	NONE
3	THE IDENTIFIED PROBLEM IS INADEQUATE COVER	NONE	9

All choices <A> only if >1 <G> Print <P> Change/rerun <C>
Rules used <line #> Quit/save <Q> Help <H> Memo <F10> Done <D>

```
EXSYS Pro ============ ** CHANGE INPUT DATA ** ============

 1  EXPOSURE CONDITIONS ARE VERY DAMP
 2  CRACK PATTERN IS MAP CRACKING
 3  SURFACE TEXTURE IS ALKALI SILICA GEL PRESENT
 4  CHLORIDE CONTENT (% cement mass) = .15
 5  pH VALUE OF COVER CONCRETE = 9.3
 6  FREE CARBONATION DEPTH = 5
 7  DEPTH OF COVER (mm) = 14.8
 8  ALKALI CONTENT (kg/m3) = 7.6
 9  FREE EXPANSION STRAIN = .072

Enter number of line to change  <O> for original data  <R> to run the data
<H> for help  Memo <F10>
```

R.C. SLAB

```
EXSYS Pro ============ ** RESULTS ** ============
                                                              VALUE
 1  THE IDENTIFIED PROBLEM IS ALKALI-AGGREGATE REACTION          8
 2  INSUFFICIENT DATA TO IDENTIFY THE PROBLEM                    5

All choices <A>  only if >1 <G>  Print <P>  Change/rerun <C>
Rules used <line #>  Quit/save <Q> Help <H> Memo <F10> Done <D>
```

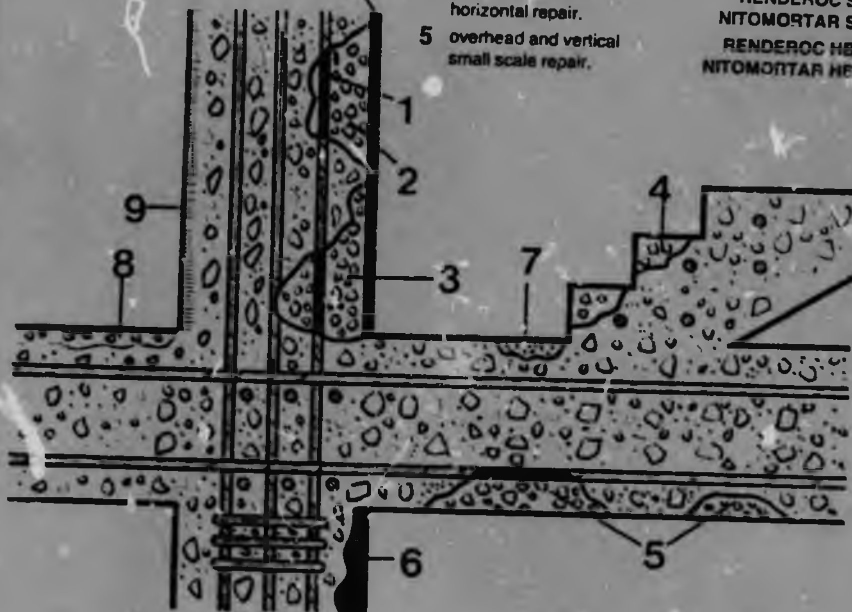
APPENDIX B : REFERENCES ON REPAIR SYSTEMS

R1/1

Fosroc

Concrete Repair & Protection

1	anti-corrosion primer for steel reinforcement.	NITOPRIME ZINCRICH
2	large scale verticle repair - non structural.	RENDEROC HB
3	large scale vertical repair	RENDEROC
4	abrasion resistant horizontal repair.	RENDEROC S NITOMORTAR S
5	overhead and vertical small scale repair.	RENDEROC HB NITOMORTAR HB
6	blowhole and fairing coat.	RENDEROC FC
7	ultra fast small patch repair.	NITOMORTAR FC NITOMORTAR PE
8	bonding agent, new concrete to old.	NITOBOND EP
9	impregnating protective sealing coat.	NITOCOTE SN502
10	decorative and protective coatings.	NITOCOTE DEKGUARD



"ATTACK UNDER ARREST"

FOSROC manufactures and supplies a comprehensive range of high performance cementitious and polymer repair compounds and protective coatings. With over 10 years proven track record, continuous research and development, supported by a professional sales team, FOSROC can place concrete attack .... under arrest.

Repair Compounds

- Single Pack Products
- Shrinkage Compensated
- Ease of Application
- Low Permeability
- Durable

Protective Coatings

- Carbonation & Chloride Protection
- Low Dirt Pick Up
- Single Pack Products
- Breathable
- Range of Colours

A total, lasting system, from *the* South African leaders in concrete repair and protection.

Fosroc

JOHANNESBURG
Reg. No. 73/01809/07
PO Box 3910
Alrode, 1451
Tel: (011) 908-1980/6
Fax: (011) 908-2749

CAPE TOWN
PO Box 22
Blackheath, 7581
Tel: (021) 905-1117

DURBAN
PO Box 477
New Germany, 3620
Tel: (031) 72-4379

PORT ELIZABETH
PO Box 13266
Humewood, 6013
Tel: (041) 53-1775

WELKOM
PO Box 769
Welkom, 9460
Tel: (0171) 5-1351/2

systems for new structure stability!

Hilti repair mortar is so easy to use.
It's an epoxy-resin bonded repair mortar and solvent free. Available in handy, easy-to-use packs, it has outstanding bonding properties and is so easy to apply. For instance, it can easily be used on a ceiling, can be smoothed down to virtually 0 mm and can be worked easily even after curing. Another advantage, it cures stress-free.

The injection system from Hilti is the economical solution to crack problems.
Hilti's easy-to-use injection system allows the workman on-site to repair cracks in concrete; without calling in specialist contractors. Controlled injection is easy because the mortar is visible in the applicator. Hilti's injection system gives reliable, permanent crack filling with high mechanical strength and excellent resistance to chemicals.

R2/1

CRACK REPAIR MADE EASY/"PLUSBOND 25" TM

A typical repair using PLUSBOND 25

"At long last an easy to use structural repair system that saves time and money"

As technology in the construction industry improves, new methods of carrying out particular tasks are developed. These methods are usually introduced for one of three reasons.

1. Improved quality of finish.
2. Improved speed of application.
3. Improved cost effectiveness.

SEALOCRETE LTD. A (B.S.5750) Company have recently launched a new product for structural repairs to Brickwork, Blockwork, Stonework and Concrete.

PLUSBOND 25 has been developed by a company actively involved in structural repair work (Resin Plus U.K.). It is now available in kit form with full application instructions and is therefore suitable for specialist contractors and jobbing builders alike.

PLUSBOND 25 can be used as a direct replacement of the conventional concrete repair method of pressure injecting liquid resins. It is faster, more cost effective and provides a far superior finish, the latter enables this system to be used in areas where previously only re-stitching of Brickwork would suffice such as listed buildings.

PLUSBOND 25 is also very effective for dowel reinforcement enabling invisible reinforcement of unstable buildings in a fraction of the time required by conventional methods. **PLUSBOND 25** can also be used for cavity wall tie replacements.

One day training courses for an approved applicator list are under way. For details please contact Sealocrete training department

Sealocrete®

For Technical brochures, advice and sales contact

SEALOCRETE PLA LTD 0706 352255
GREENFIELD LANE ROCHDALE OL11 2LD

For contract quotations contact

RESIN PLUS U.K. 0992 893 909
91 NORTH ST NAZEING EN9 2NJ
FAX 0992 893909
24 HR MOBILE 0831 490993

R2/2

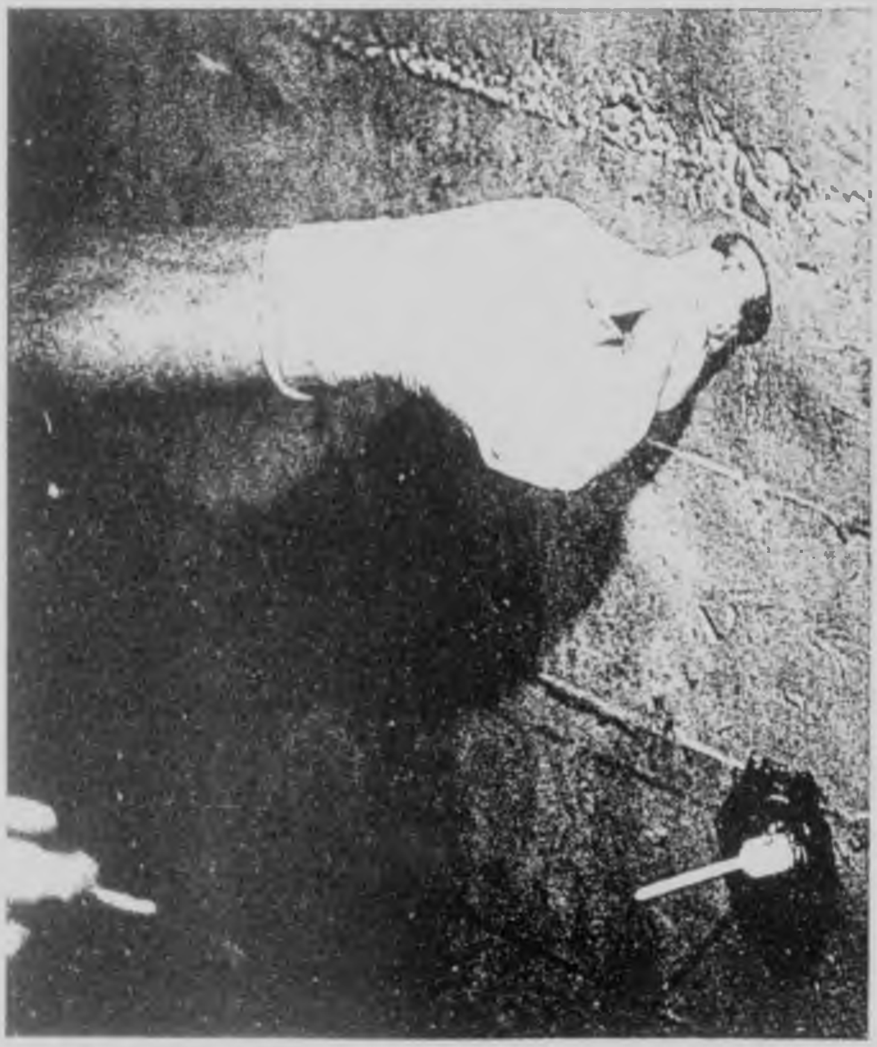
Cracks in concrete are sealed permanently and safely with the reliable Hilti injection system.

Cracks in concrete can also jeopardize a structure However if discovered early and treated properly they can be effectively eliminated

Settlement also causes cracks Hilti's injection system ensures safe and lasting sealing of cracks.

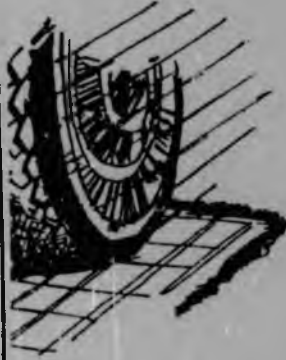
Ceiling cracks from overloading: the easy-to-use crack injection system from Hilti can solve this problem economically.

Design errors too, such as incorrect specification, or poor workmanship can effect the service life of structures. In most cases, early repair of resulting cracks is the answer



An incorrect joint gap caused this crack. Using the Hilti injection system, cracks up to a width of 5 mm can be reliably treated

ULTRACRETE
RAPID SET MORTAR



FOR *FAST* KERB AND MANHOLE REPAIRS

READY FOR TRAFFIC IN ONLY 45 MINUTES

More details from

instarmac

Unit 10E & 10B Castle Vale Industrial Estate, Maybrook Road, Minworth, West Midlands B76 8AL Tel: 021-351 4440 & 5560

31 on express enquiry card

concrete repairs & protection?

Whether its renovation or restoration Don Construction Chemicals are the answer!

Any horizontal or vertical repair problems can be solved with one of the many specialist resinous or cementitious products from one of the top names in concrete repairs and protection.

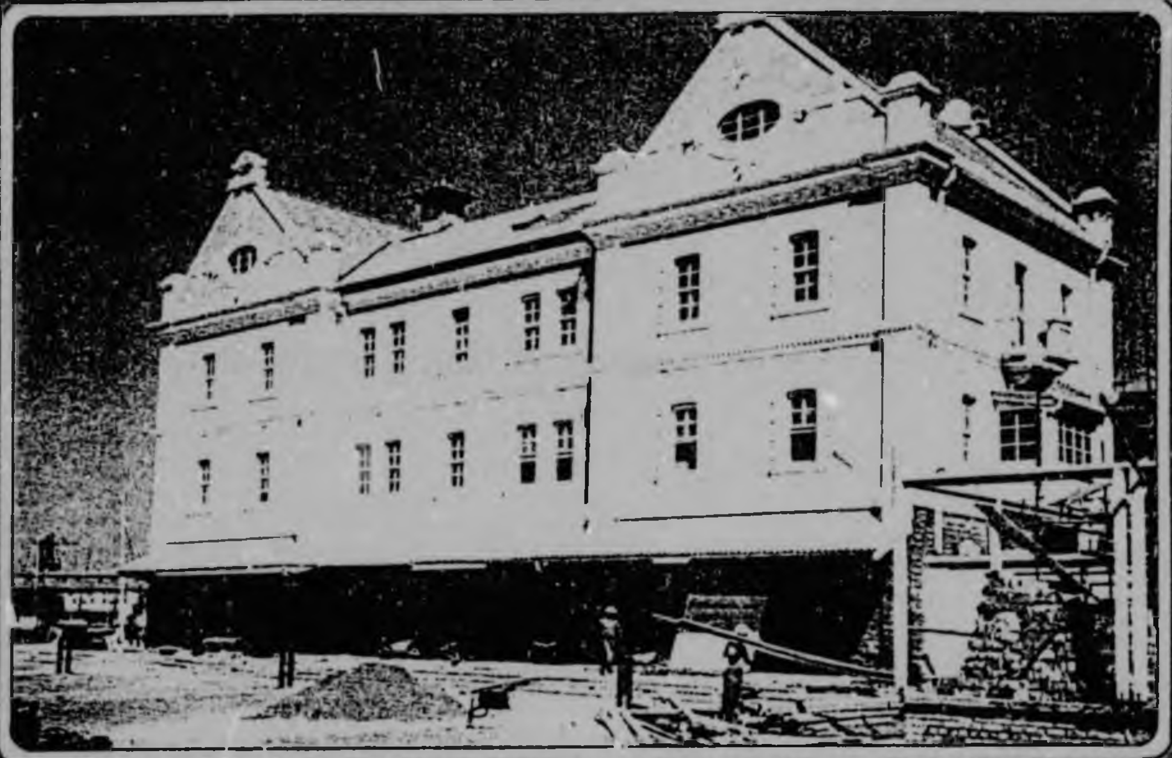
QUICKMAST RANGE
Resin based Mortars, Grouts and Coatings
CEMPATCH & SETCRETE
Cementitious Mortars, Grouts and Waterproofing Systems
The total answer to all your building repair needs . . .
For all the facts contact . . .

Other products are available for Flooring Materials, Chemical Fixings, and Cement Admixtures

Don Construction Chemicals Ltd

Jossey Lane, P O Box 22, Scawthorpe, Doncaster, Yorkshire DN5 0DT
Telephone 0302 820888 Telex 547102 Fax 820997 ext 3344

32 on express enquiry card



Old Captain's Building, East Pier Waterfront. Refurbishment of internal walls.

Architects: Munnik, Visser, Black, Fish and Partners
Main Contractor: Yusuf Arendze & Sons

Applicator: Trevicon
Contact: M.B. Fioravanti

Toupret BBF skimmed directly onto old gloss enamel surfaces and new plastered sections to make good. No primers or stripping needed.

Toupret Cachet Bleu skimmed onto BBF to smooth down surfaces – very economical.

Only one coat of paint necessary to finish walls. Toupret adherence to gloss paint 6,50 kg c/²

With Toupret, a batching plant is unnecessary – the powder is simply mixed with water on the spot and applied.

TOUPRET

A mineral plaster with a painted finish
As tough as concrete and extremely elastic.

Easy to apply by trowel or roller, saving time and money.

Toupret S.A.
Ferguson Street
Bellville. 7550
Tel & Fax (021) 948-2578

Continental Decorative Plasterers
P.O. Box 92,
Sanlamhof, 7532
Tel (021) 948-2222
Fax (021) 948-2578

R7/1

APPENDIX C : REFERENCES ON SPECIAL INSTRUMENTATION

Building inspection

A versatile, low-priced inspection endoscope for architects, surveyors, builders and other industrial users has been introduced by P. W. Allen & Co.

Less than 10 mm in diameter, the Interscope can be inserted through very small openings to inspect cavity walls, floor and ceiling voids, pipe runs, ducts, box girder and similar, normally inaccessible areas in buildings and other structures. The combination of an efficient lens system with a powerful lamp which is protected within the tip provides a clear, close-up image of interior features under inspection. For record purposes, the eyepiece can be linked to a 35 mm camera using a special adaptor.

The working length of the Interscope is 350 mm, with an overall length of 400 mm. The outside diameter of only 9·65 mm makes possible disruption-free inspection through existing openings or small drilled holes.

Designed and built in the UK, the instrument is robustly made with a rigid outer tube of stainless steel. Operated by mains or battery, the Interscope is available as a standard kit in a handy custom case.

For more information contact P. W. Allen & Co., 25 Swan Lane, Evesham WR11 4PE, Worcs. (tel: 0386 401 48).

B4/1

The low-cost inspection kit

RESEARCH Instrumentation cc of Sandton is distributing the HSW-Econoscope-Kit, a low cost kit developed for inspections for which the use of cold-light endoscopes is too expensive.

The 315 mm long, 9 mm diameter Econoscope is used for preventative maintenance work and for non-destructive material examination.

A 90° lateral direction of view, fixed focussing from 7 mm to infinity and illumination by a 6 V halogen lamp enables visual inspection of hollow bodies and cavities which otherwise are not accessible without disassembly.

Fields of application are mechanical engineering, vehicle inspection, preventative maintenance of technical plants and examination of building structures.

The Econoscope with fixed co-axial cable and built-in switch can be mains-operated and a combined transformer/charging unit in a Europlug case with a 220 V connection is supplied as standard equipment.

HSW - Econoscope

Other standard equipment includes a spare 6 V lamp and a case for transport and storage.

For non-mains operation, a maintenance-free 6 V rechargeable battery which allows a continuous working period of up to three hours, is available as an accessory.

For more details contact
Research Instrumentation cc
Tony Salvage
P.O. Box 1148
Gallo Manor
2052
Tel: (011) 802-5060

B4/2

Field portable Borescope System

Portable and affordable Videopac is the answer

AT last, a truly field-portable borescope system has arrived on the scene which fits into your budget as easily as it slips over your shoulder.

Welch Allyn's new VideoPac System is the portable addition to the VideoProbe 2000 line you've been waiting for.

VideoPac's joystick articulation allows one person to manipulate the probe and control articulation.

You can either run the system off its own 12 V battery for a minimum of 45 minutes of continuous operation, or you can hook it up to an external 12 V source (such as an automobile battery) for longer operation.

The VideoPac can also operate off a 220 line voltage indefinitely.

Another feature of the VideoPac is its high quality, crystal-clear image. The system has a 90° field of view, 10 to 100 mm depth of field, and more than 248 K pixels of resolution.

VideoPac's probe can be immersed in gasoline and aviation fuels and operates without cumbersome tethers or wires.

For push-button documentation, attach VideoPac to any standard video recording device including videotape, hard copy printers and video disc.

For more details contact
Charles Perrie
SA X-Ray (Pty) Ltd
Telephone
(011) 622-3890/1
Fax (011) 615-8505

Industrial inspections by cost effective and versatile means.

THE HSW TEW range of sectional Rigid Borescopes provide an extremely cost-effective and versatile means of carrying out industrial inspections where the instrument must be very long and where high levels of illumination are required.

The endoscopes are modular in design, allowing very long instruments to be assembled on site and yet easily carried and transported. The tips carry extremely compact and powerful lamps of the latest design which enable large vessels, chambers and headers to be inspected with ease.

Inspection of large vessels or cavities can be carried out through small access holes. Owing to the fact that direct illumination of the cavity is produced by a high intensity Quartz tip of the instrument, larger cavities can be inspected than with Fibre-Optically Illuminated Endoscopes.

Available in four diameters: 9, 14, 18 and 24mm
Working lengths 500mm to 25.000mm.
Interchangeable viewing heads with directions of view, 0°, 0° (wide angle), 45°, 90° and 100° retro.
Adjutable angle of view on some sizes.
Extension tubes 500mm to 1500mm.
Five interchargeable eyepieces.
Monocular, Binocular, zoom, 45° and 90°
All metal construction, outer tubes stainless steel.
Temperature resistant to + 120°C.
Pressure and water proof on 14mm diameter and above.

For more details contact:
Mr. Tony Salvage
Research Instrumentation
P.O. Box 1148
Gallo Manor 2025
Sandton
Tel: (011) 802-5060

C1/1

The picture demonstrates how the new Proceq pull-off tester is used on site.

DIGITAL PULL-OFF TESTER

The Swiss based company of Proceq has introduced a digital measuring system for toasting the surface strength of concrete.

Known as the Dyna electronic Pull-Off Tester, the instrument displays all relevant test data on a large LCD screen, and a pacemaker predetermines the increase of load per second and setpoint/actual value are continuously compared by two flowchart bars.

The peak value is recorded and, where necessary, can be printed out.

The Dyna system is mains independent, and the whole weighs 4.25kg (indicator 0.75kg and pull off device 3.5kg) and allows constant smooth load increase via an even-running crank drive.

ENTER ENQUIRY CODE 130
or FAX INT (+32) 1 383 99 14

Concrete testing

CNS Electronics recently launched its resistivity meter, developed by Taywood Engineering and designed specifically to measure the resistivity of concrete. Using a standard Wenner linear four-probe array, a flat-topped a.c. wave-form for the current source and sophisticated electronic circuitry, a true measure of the d.c. component (i.e. resistance, not impedance) of resistivity is measured. The resulting measurement is not frequency dependent.

There are four basic ranges of full-scale measurement possible: 0-2kΩcm, 0-20kΩcm, 0-200kΩcm and 0-2MΩcm. The actual full-scale reading is 1999, and an over-range indication is given for readings greater than 1999. A 10-turn dial (the 'spacing' control) allows the probe spacing to be entered, resulting in a true measurement of resistivity in Ωcm. The range is 0-10cm (i.e. 1cm/turn).

In addition to resistivity ranges, the RM has four ranges of a.c. resistance measurement (again, resistance not impedance) as measured between the two current probes, selected by a 'function' switch. They are: 0-20kΩ, 0-200kΩ, 0-2MΩ and 0-20MΩ. By setting the 'spacing' control to 1.59cm, and using a four-probe technique, additional a.c. resistance measurements in the range of 0-200Ω and 0-2kΩ may be made, using the two lower resistivity ranges.

Full details may be obtained from CNS Electronics Ltd., 61-63 Holmes Road, London NW5 3AL (☎ 071-485 1003).

C7/1

NEW MICRO COVERMETER
The FIRST CHOICE for rebar location

If you need to measure accurately the depth of reinforcement below hardened concrete, then the new Micro Covermeter should be your first choice. Just consider these features.

- FIRST microprocessor Covermeter rebar locator
- FIRST to measure 360mm depth - BS1881:204
- FIRST with digital display facility for either high tensile or mild steel
- FIRST pocket-sized unit - weighs only 1kg
- FIRST unit with keypad operation
- FIRST for value - more features for less cost

Other features include

- Quickscan low cover audio alarm facility to check if rebars have insufficient cover
- Automatic sizing of bars
- Software can be updated simply and quickly
- Ignores magnetic aggregates

Covermeter is the trade mark of Kolectric Ltd

Make the MICRO COVERMETER your FIRST CHOICE

Kolectric Limited. Dean International House, Thames Industrial Estate, Marlow, Bucks SL7 1TB, England
Telephone: (06284) 77266. Telex: 846976. Fax: (0628) 890178.

New REBAR LOCATOR PROFOMETER 3 with Microprocessor

a PROCEQ product from Switzerland

Very simple to use
A short, audible signal sounds immediately the probe is located over a reinforcing bar.

Very high Resolution
The reinforcing bars can be identified individually even when they are located very close together.

Optimized Probes
Measurement of concrete cover to 90 mm using spot probe, to 220 mm using depth probe.

Extremely Accurate
Measuring uncertainty in the important measuring range up to 50 mm is only ± 1 mm!

Fast Scanning
1 m² can be scanned for inadequately covered rebars in 1 minute by preselecting a limiting value.

Measuring Rebar Diameter
Rebar diameter is digitally displayed using a special probe, accuracy ± 1 mm.

PROCEQ SA
Riesbachstrasse 57
CH-8034 Zürich

Tel. 01/47 78 00
Telex 817 118 prc ch
Fax 01/47 99 14

proceq

Proceq's new test hammer is being launched for general use.

The Netherlands institute TNO was commissioned to review methods of testing pointing in masonry. After intensive studies, the institute found the most suitable method to be the Schmidt building material test hammer Model P, produced by the Swiss manufacturer Proceq. For this purpose, the test hammer is fitted with a special head for testing in the mortar joint, the hammer is now being launched for general use.

M3/1

Vibration analysis

A low-cost quartz accelerometer (model 3126A), called the 'Modalometer', has ben introduced by Sandhurst Scientific Company. Specific advantages allow economic modal analysis and multipoint vibration measurement on large structures.

A device with this level of performance and simplicity of use now makes comprehensive multipoint analysis a viable proposition. Additionally, the particular design advantage of a built-in amplifier eliminates problems normally associated with long cable runs and the necessity for extra expense of low noise cables.

The acceleration range is ±50g, with a frequency response of 1Hz to 3kHz and sensitivity of 100mV/g.

The accelerometers require a constant current input of 2mA to drive them, and the signal output is 0-5V proportional to the full range of the sensor. Output impedence is 100Ω.

The 3126A measures 16mm in diameter and 29mm in height and weighs 56 g. They are fitted with 10-32 THD coaxial connectors, are non-magnetic, and shock overload protected up to ±1000g.

The standard units feature self-adhesive mounting pads for easy installation. Alternative tapped mountings can be specified if required.

The 3126A is the latest in a family of quartz element accelerometers available from Sandhurst. In the range there are five other models, including a high performance triaxial model (3013A), a general-purpose top connector model (3010A), two miniature units (3015A, 3101A), and an ultra high shock version (3200A) for ranges up to 100 00g.

More details are available from Mr L. Hobbs, Sandhurst Scientific Instrument Co. Ltd., 68A High Street, Old Mill Parade, Sandhurst Camberley GU17 8ED, Surrey (☎0252 879 700).

VIBRATION MEASUREMENT

When a demolition contractor wants to take a building down using explosives, he has to think not only on how to place the charges and how to calculate the correct initiation sequence, but also to think about the neighbours.

Will the explosion itself produce vibrations that might damage the surrounding buildings and/or installations or is it the impact of the building hitting the ground that creates the highest vibrations? What about airblasts? Noise?

To protect himself the contractor or the developer has to measure the vibrations and airblasts created by the conditions mentioned above. This in order to show that they have carried out the job within the limits very often predetermined by the authorities.

To measure properly and accurately the need for the state-of-the art instrumentation is imperative. Nitro Consult, Stockholm, Sweden has for many years been developing and marketing instrumentation for the measurement of vibration and airblasts.

Nitro Consult offers a range of instrumentation from the single channel UVS 500 Vibration Monitor (continuous monitoring; 1 month memory) to the eight channel UVS 1608 Time History Recorder. In between those models they have the four channel UVS 1504 Vibration Monitor, which both is a time history recorder as well as a continuous monitor.

In fact the UVS 1504 records the vibration simultaneously on three different memories. One memory is used for full waveform recording with up to 96 events' memory capacity; one memory for continous peak monitoring with 2 minute intervals (1 month memory); the third memory records the peak values at 2 second intervals during 8 hours (excellent for monitoring for example pile driving.)

All [illegible] instruments measures dow[illegible]z – using standard geophones [illegible] it is possible to change them [illegible]ctronically to measure down [illegible]Hz in order to comply with the German DIN-norm.

M9/1

HYDRAULIC FAULT FINDER

A new portable test unit from Webster Instruments makes hydraulic fault finding and performance checks easier over a wide range of mobile machinery.

Connected anywhere in circuit, DHT series digital testers simultaneously measure flow, pressure and fluid temperatures under the changing system conditions induced by operating a built-in pressure loading valve.

Based on a microprocessor, the tester gives the extra accuracy and precise readings associated with digital displays and gives the operator a 'slow update' option for the display which he can select when rapidly fluctuating values would otherwise make readings difficult.

There is a choice of four models in the DHT series covering internal flow ranges of up to 0-800 l/min and a temperature range from 0-120 deg C.

ENTER ENQUIRY CODE 206
or FAX INT +44 487 843104

A DHT series digital hydraulic tester.

Underground sewer pipe locator

A REVOLUTIONARY system for surveying drains and locating problems underground in a very short time with no costly excavation and with complete accuracy, is available from PREJ Instrumentation.

The Tracka system consists of a battery-operated transmitter which is attached to the end of normal sewer rods and pushed down the pipe, and a small portable receiver which the operator uses to locate the exact position of the underground transmitter. Operation of the system is simple: a series of sweeps with the receiver rapidly establishes the position of the transmitter which may lie up to 6 m below the ground. The amplifier is then turned down to pin-point the exact position of the transmitter to a spot 20 cm in diameter or less.

The transmitter is designed for the rough, dirty and wet conditions of a sewer, and emits signals which penetrate through a wide range of soils, clays, sands, concrete and even reinforced concrete. The receiver is designed to respond only to the transmitter, and can be used not only to tell when the operator is directly above the transmitter, but also to indicate the depth at which it is lying. Both the transmitter and the receiver are powered by standard batteries with operating lives of several hundred hours without any external connecting wires.

M12/1

CONDENSATION OR RISING DAMP?

NEW

PROTIMETER BASIC DAMPNESS KIT

where the **Protimeter Mini** also serves as a **Salts Detector** and the **Protimeter Digital Hygrometer** (with plug-in surface-thermometer and built-in condensation slide-rule) helps you to avoid mistaking *Condensation* for *Rising Damp*.

MEASURES CONDENSATION BEFORE YOU CAN SEE IT

Protimeter Mini III moisture meter which will also serve as a Protimeter Salt Detector.

Protimeter Deep Wall Probes

Protimeter Digital Hygrometer with Dewpoint Slide-Rule

Moisture Probe and Lead, for awkward corners

SPECIAL INTRODUCTORY PRICE

£189

+VAT

In a Custom Carry Case – with a space reserved for the Damp Check, the condensation tell-tale.

Surface Thermometer for the diagnosis of condensation

PROTIMETER

PROTIMETER plc.,
Meter House, Marlow,
Bucks SL7 1LX, England.
Telephone: (06284) 72722.
Telex: 849305 (Pmeter G)
Facsimile (06284) 74312

SEND FOR
FREE
EXAMPLE OF THE PROTIMETER CONDENSATION SLIDE-RULE (PART OF THE DIGITAL HYGROMETER)

Pile integrity testing

A service for the cost-effective, non-destructive testing of the structural integrity of concrete piles is available from Acoustic Technology Ltd.

Unlike conventional static load testing methods—which, because of cost and time, usually allow only random testing of selected piles on a site—the ATL system gives civil engineers a facility for testing *in situ* up to 30 piles/day.

The system uses the principle of dynamic response measurement to examine the integrity of concrete piles by determining the effective constructed length, the cross-sectional continuity, the quality of the concrete, and the elastic stiffness of the pile in the ground.

On-site results are obtained using high-accuracy portable equipment which incorporates some of the latest microprocessor-controlled data acquisition and analysis techniques.

This rapid test capability signficantly reduces the unit cost without risking damage to the pile itself. The service is suitable for most concrete and grout piles.

With the low unit cost, the constructed quality of all piles on a site can now be evaluated, giving full, cost-effective assurance that all are of sound construction.

ATL provides a wide range of noise control, vibration engineering and related services for the construction industry. In addition to pile integrity testing the company's consultancy services include pile design assessment, foundation dynamics, and pile and blasting vibration monitoring.

ATL's electro-dynamic shaker positioned on the head of a concrete pile

Full details are available from Acoustic Technology Ltd., 58 The Avenue, Southampton, Hants. SO1 2TA (tel: 0703 37811).

Frankipile introduces sonic integrity testing

Frankipile has become the first piling company in the country to invest in sonic integrity testing equipment for the testing of piles.

Following the recent visit by Francois van Weele of the Institute for Foundation Verification of the Netherlands, Frankipile has purchased the IFT system.

According to van Weele, sonic integrity testing is conducted on between 70 to 80% of the cast in-situ piles in the Netherlands and its popularity is increasing throughout Europe.

The test is a powerful method of quality control in foundation engineering. It is used to verify the integrity of foundation piles after installation and can be applied to prefabricated piles, as well as to cast in-situ piles of any size and type.

According to Frankipile the sonic integrity test will enable the company to check the pile length and to detect any major defects in the pile shaft.

The tests are conducted by pressing a transducer onto the top of a pile while striking the pile head with a hand held hammer. The field computer registers the impact of the hammer followed by the response of the pile and shows both on the display. The signal can be stored in the memory of the system and, together with other information, such as pile number, date, time, site, amplification factor and filter length can be reproduced at a later stage. Data for up to 500 piles can be stored by the unit.

Initially Frankipile will use the new system on its existing projects throughout the country but it will also make the service available on a hire basis to the industry generally.

P3/2

For Improved Quality Assurance of Deep Foundations

Two Testing Tools for Civil Engineers Routinely Applied Worldwide

Pile Driving Analyzer™

Measures...

- **Hammer performance • Driving stresses**
- **Pile Integrity • Bearing capacity**

Significantly faster and less expensive than static testing, our PDA gives more information to improve quality control and provides immediate results for many test piles per day. PDA contains a built in "expert system" to assist the new engineer. The world's original dynamic pile test system is in routine use on over 2,500 sites yearly for driven piles and drilled shafts.

Pile Integrity Tester™

Quickly evaluates integrity of piles or drilled shafts at very low cost with a non-destructive test, using a hand-held hammer and one person operation. Sturdy device is compact (1.6 kg - 4 lb.) and extremely user-friendly, with touchscreen menu inputs. Automatically determines shape for easy interpretation of results.

Representatives Worldwide

Pile Dynamics, Inc.
Since 1972

4535 Emery Industrial Parkway • Cleveland Ohio 44128 USA
Tel (216) 831 6131 • Fax (216) 831 0916

R4/1

NEW Manufactured in South Africa

Precision Measuring Wheel

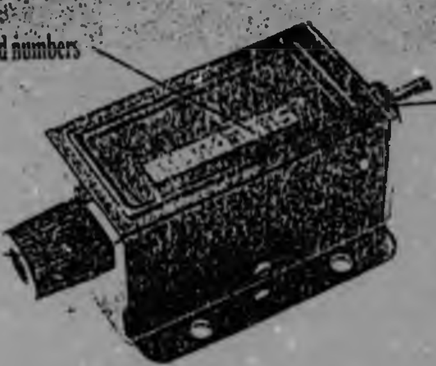
Roto-sure is a robust measuring wheel designed to cater for tough conditions.

All the components of roto-sure are manufactured to a high standard of quality.

Roto-sure:

- measures up to 10 000 metres in metres and decimetres
- will add and subtract distances
- makes measuring convenient
- extremely cost effective
- back-up services
- 12 month conditional guarantee

The Roto-sure is utilised by various organisations eg. Fencing Contractors/Farming and Agricultural concerns/Surveyors/Road Markers/Civil Engineers/Pipe and Cable layers and is ideal for Sports field layouts etc.



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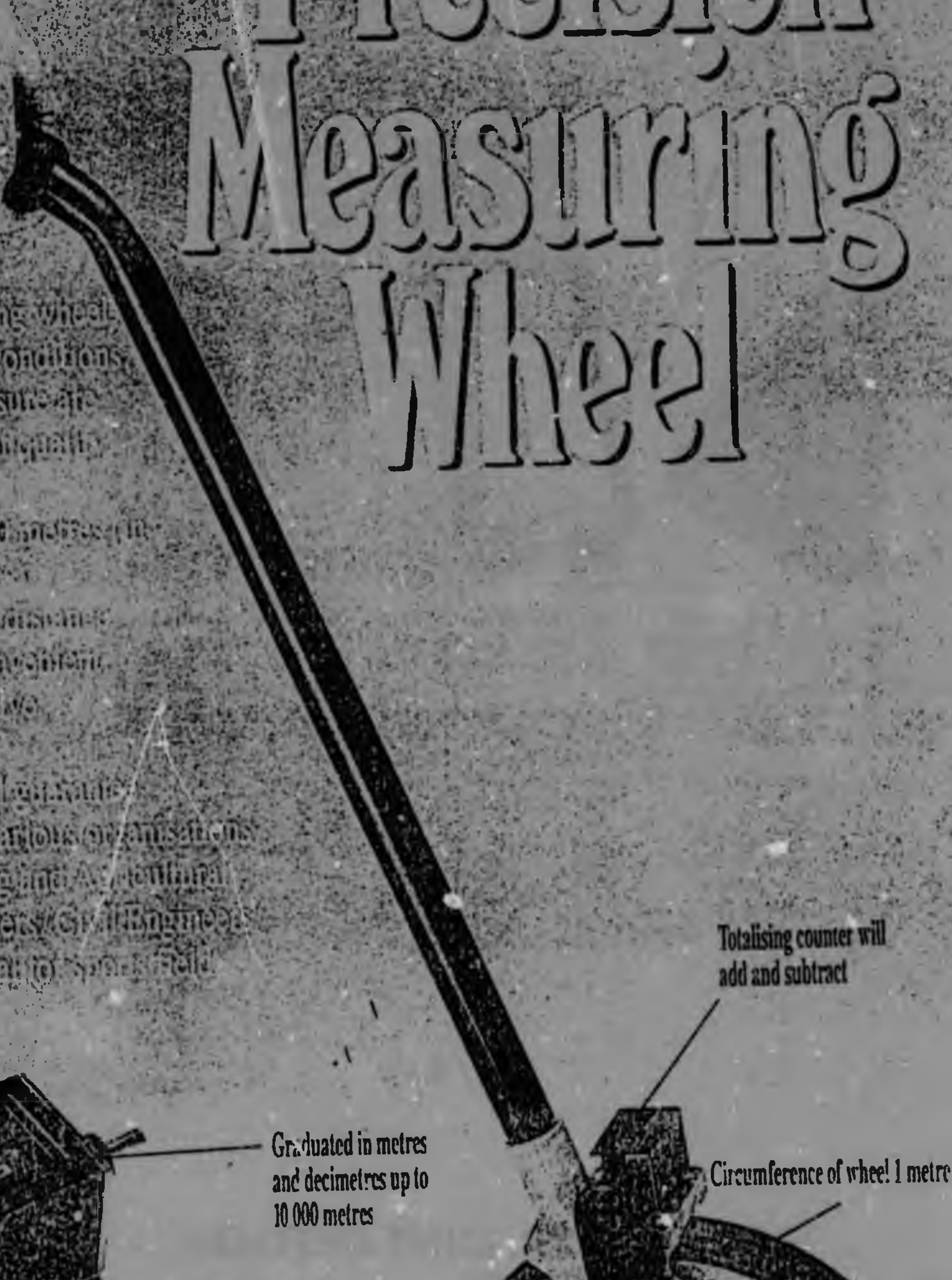


ROTO-SURE®

MANUFACTURED BY UNITED MATRIX PLASTICS TEL (011) 970-2403/975-1337 FAX (011) 394-3074

(THE COMPANY RESERVES THE RIGHT TO IMPROVE THE DESIGN WITHOUT NOTICE).

Inquiry No AZ3490

DESIGN GRAPHICS

Measuring of corroded metal pipes and tanks

52/1

The Panametrics Model-26 a highly advanced and low-cost ultrasonic corrosion gauge

FOR high performance and quality measurements on corroded or eroded metal pipes and tanks, the highly advanced Panametrics Model 26 gauge is your answer.

This low-cost unit utilizes ultrasound to make nondestructive thickness measurements when only the outside surface is accessible.

The hand-held Model 26 makes full use of its sophisticated microprocessor to offer more features than could previously be expected from a corrosion gauge of its size and weight.

Automatic probe recognition, alarm setpoints, transducer temperature compensation, and 'fast' and 'min' modes are just some of the features that make it ideally suited for most corrosion applications.

Automatic V-path correction ensures accurate and repeatable thickness readings measurements over a range from 0.5 mm to 200 mm.

The Model 26 has a colour-coded keypad with a large LCD display to make corrosion gauging simpler than ever before.

Panametrics also has available the Model 26DL which offers all the features of the 26 plus an internal datalogger and RS-232 communications port.

For more details contact
Steve Liversedge
SA X-Ray (Pty) Ltd
Telephone
(011) 622-3890/1
Fax (011) 615-8505

COATING THICKNESS GAUGE

53/4

POSITECTOR 2000

The best instrument for measuring any non-magnetic coating, such as paint, plating, galvanising on steel substrates.

SIMPLICITY

- One hand operation
- No dials or switches
- Direct digital read-out
- Non-destructive measurement
- Range 0-1 500 microns
- Competitively priced

Evanel (Pty) Ltd

P.O. Box 1505 Rivonia 2128
Telex: 4-26241
Tel: (011) 802-3320 Fax: (011) 804-2973

Coating thickness testers

THE Deltascope MP3 and the Isoscope MP3 are robust, compact, new technology coating thickness testers with up-to-date communication and documentation capabilities.

The testers can be used to measure "in the field or on the production line." Results can be logged on a printer or a computer. The testers are also suitable for Statistical Process Control (SPC).

By using modern microcomputer techniques, the instruments are able to retain stored values on switch-off. These can be retrieved later at another location via the display, a printer or a computer.

The testers can store up to 4 000 values in four memories. Each memory takes 1 000 readings which can be subdivided into batches.

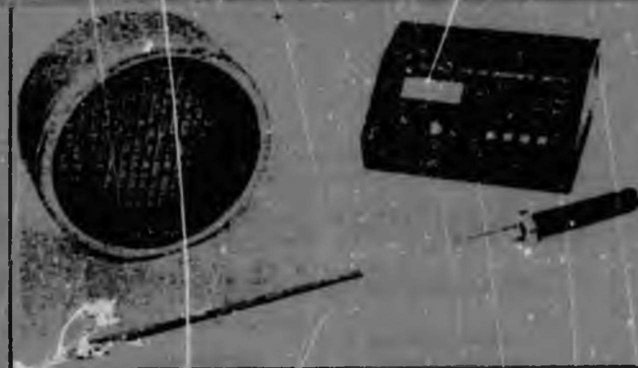
Data can be retrieved as batch means or individual values. Measurements from different components or different areas on the same component are separately stored.

Deltascope MP3 can be used to measure coatings used on iron and steel such as cadmium, chromium, copper, zinc, paint, enamel and plastics.

The Iscoscope MP3 can be used to measure coatings such as paint, plastic and rubber on such products such as aluminium, copper and zinc. It can also be used to measure anodized coatings on aluminium.

Quote CC02-200 on R/S card

The new technology coating thickness testers are compact and robust in design.



S[illegible]'s new [illegible] electrostatic [illegible] diagnostic kit.

S3/

Powder coating kit

SHEEN Instruments has now simplified the operation of its electrostatic powder coating diagnostic kit so that it can be used with ease by operators on the powder coating line.

The product is available locally from Prei Instrumentation.

Originally developed by the Wolfson Electrostatic Unit at Southampton University, it provides the measurements which instantly identify many causes of poor coatings and will thus optimise the performance of any powder coatings system.

To do this, the powder coating diagnostic kit supplies three essential measurements, namely true gun voltage, charge-to calculate charge:mass ratio and workpiece current.

The kit consists of a redesigned portable battery-operated electrometer, a Faraday cup with ion trap and a high voltage probe.

Quote CC02-201 on R/S card

S3

S3a

The Thickness GAUGE of Tomorrow is here TODAY

Sonimex 2000 is designed to measure the Thickness of STEEL, ALUMINIUM, COPPER, GLASS, PORCELAIN ACRYLIC RESIN, PLASTICS, etc.

SIMPLICITY:

- No Calibration Required
- Auto-Hold/Auto-Off
- Mass – 230 gm
- Range 1,3 - 300 mm
- Non-Destructive Measurement
- 4 Digits LCD Display

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53/2

THE 4 IN 1 COATING THICKNESS GAUGE

THE QuaNix 1500 outstanding features are:-

- ★ One hand operation
- ★ Automatic calibration
- ★ No calibration shims required
- ★ Just place & read
- ★ No plugs - no cables
- ★ For Ferrous substrates
- ★ For Non-ferrous substrates
- ★ Measuring Range of 0 - 5000µm
- ★ Twin LED digital display
- ★ LOW COST

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53

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- Particle/Asbestos Boards
- Diameter/Position Guaging

Measuring technique based on:-

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53

53/3

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Viscosity Cup
Acc. to ASTM/D-1200 (FORD). Deliverable with fixed nozzles and for interchangeable nozzles, no. 1/2/3/4 or 5.

Krebs-Stormer Viscometer
With digital reading for non destructive measuring of all non magnetical coatings on iron and steel. Range 0-1000 um.

COATEST Thickness Gauge
With digital reading for non destructive measuring of all non magnetical coatings on iron and steel. Range 0-1000 μm.

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- FINENESS GAUGES
- BIRD FILM APPLICATORS
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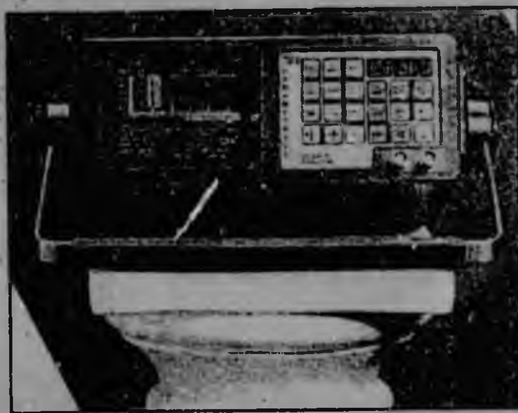
CAROLYN or LUCIEN

024

55/1

The Epoch II ultrasonic flaw detector

For advanced testing of materials & documentation of results



SA X-RAY is pleased to announce the introduction of the new version of digital portable ultrasonic flaw dectors...EPOCH II. This flaw detector has been designed to meet the challenges which inspectors will face in the 90's with testing new advanced materials and documenting results.

Epoch II is a versatile instrument which can be used in virtually any industry such as: nuclear, aerospace, advanced materials, weld inspection testing, and NDT training schools.

Panametrics is very proud to be the pioneer of portable digital ultrasonic flaw detection. In developing Epoch II, much time was spent listening to comments from present users of ultrasonic flaw detectors. Our primary goal in designing this unit was to simplify digital technology. The result...an advanced instrument which is compact in size, light-weight and most importantly, easy to use. With the Epoch II you have direct access to a variety of standard and special functions.

Some of the features include: ability to store 40 transducer setups, waveforms, and DAC curves; Status readout displays all system functions with preset values. Operator can display both A-Scan and status display simultaneously in split screen mode; Superior minimum range 1.8mm (full scale longitudinal velocity in steel); Thickness readout resolution of 0.01mm.

Options include: B-Scan with encoder imput for location information; Distance Amplitude Correction (DAC) Curve; Interface Gate for immersion testing applications or echo-to-echo thickness readings.

For more details contact Charles Perrie SA X-Ray (Pty) Ltd.
Telephone (011) 792-2611 or (011) 792-4740
Fax (011) 792-5553

51/1

Component testing

FaAA Products Corporation has recently developed SSam-2, a novel miniature material sample removal system. SSam-2 removes physical specimens for metallurgical analysis with a negligible effect on the structural integrity of most components because of the geometry and smooth finish of the depression left by the process. Samples can be removed from remote locations inaccessible by conventional methods and from components where sampling was not previously possible.

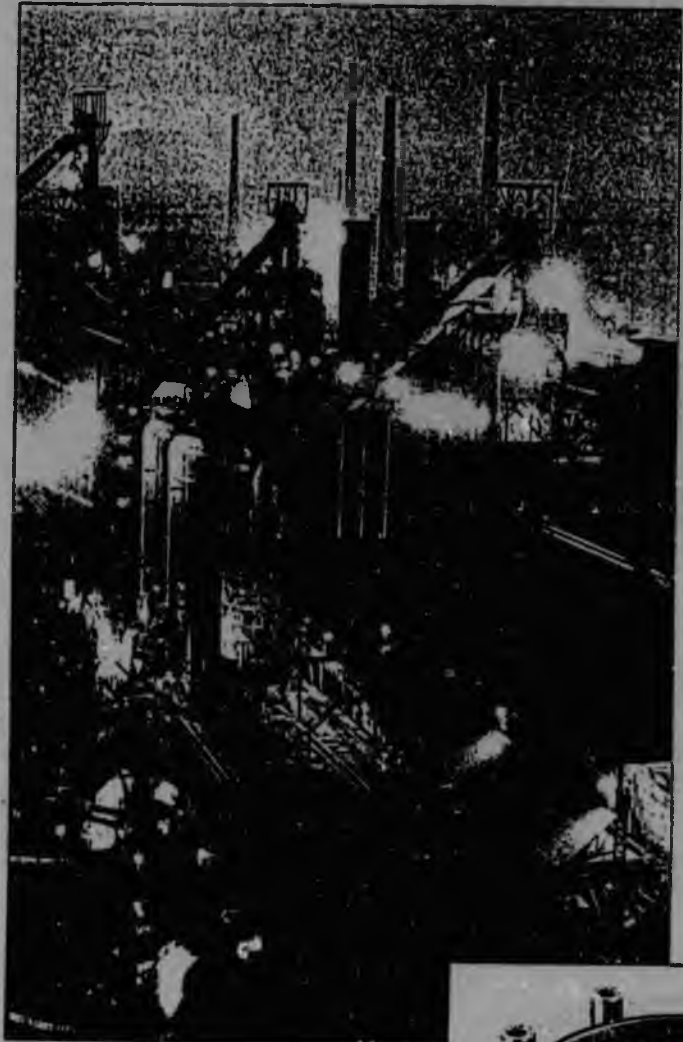
Operated remotely from a computer control console, SSam-2 (Surface Sampler) removes a thin, lens-shaped surface specimen using a hemispherical shell cutter. Its fine grinding process separates a sample from the base material without plastic deformation or thermal degradation. Samples up to 2.5mm thick × 25.4mm in diameter can be obtained. The device has been used inside turbine bores and piping as small as 76.2mm in inside diameter.

SSam-2 can be used to remove samples from internal or external surfaces of components such as piping, structural welds, pump casings, rotating machines, and pressure vessels. Analysis of these samples permits evaluation of the nature of surface flaws, material chemistry, microstructure, surface corrosion or deposits, and mechanical properties of the material.

This ability to remotely remove material samples in an essentially non-destructive manner has broad application in critical equipment evaluation. While other methods exist for excavating samples of material using a variety of cutting processes and equipment, the developers are aware of no other device that permits this sampling to be performed in such a superficial fashion that there is usually no need for repair of the sampled component.

Acute problems exist in assessing aging machinery where decisions must be made regarding their continued operation without knowing their true condition. Physical specimens are critical to assessing the degradation of mechanical properties of components in service. Evaluation of this degradation makes it possible to weigh more accurately the risk of catastrophic failure against the major expense of actions required to avoid such failures.

Further information can be obtained from Dr. David Mercaldi, FaAA Products Corporation, 115 Flanders Road, Westborough, Massachusetts 01581, USA (☎ 508 366 6360).



Talk to your loadcell — by computer

Standard loadcells manufactured by Loadcell Services Pretoria can be linked to IBM compatible PCs to provide close monitoring, and immediate access to production, processing, weighing, transportation or other plant information.

This can improve overall plant efficiency and productivity, ensure minimum downtime and contribute significantly to greater economical operation.

Very affordable

Connecting loadcells to a computer can be a low cost exercise leading to the implementation of first stage automation which gives the user the flexibility to upgrade later if required.

Control and alarm systems are standard features of the system.

Locally produced software

There are a number of locally produced software packages available covering a wide range of industrial applications, such as food, chemical and pharmaceutical processing, foundries, batching and blending, skiploading in mining, paint production and belt weighing.

Advice to clients

Loadcell Services is working in collaboration with a number of software companies and is in a position to advise customers.

The software is modular and adaptable to suit any environment. Compared with alternative software installations, it is easily accessible and understandable. Large or small companies will benefit by linking their loadcells to PCs.

For more information, please fill in the reader enquiry card in this issue and post it today, or call the number opposite.

☎ Use the phone — it's quicker!

Loadcell Services Pretoria

Contact: Tony da Costa
Doug Buetow

Telephone: (012) 386-1460

T1/2

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T2/1

T2

SOLEX DIGITAL ULTRASONIC TAPES UR1000/UR2000/UR3000

UR2000/UR3000 EXCLUSIVE TO SOLEX

WORLD FIRST

A NEW DIMENSION IN MEASUREMENT TECHNOLOGY

IMPERIAL/METRIC CONVERSION. SQUARE AND CUBE FACILITIES.
MEMORY'S AVAILABLE FOR LENGTH, WIDTH & HEIGHT. 60cm-10m RANGE.
ERROR INDICATION. ACCURACY OF 1%. LITHIUM BATTERIES. AUTO SHUT OFF.

Solex's UR1000, UR2000 and UR3000 digitapes are now **available**, which incorporate all the latest custom electronics **and features**. Just point the unit in the right direction and it instantly tells you the length width or height of a room, within an **accuracy of 1%** of the displayed reading.

Model UR1000 is the basic model with readings in meters and centimeters only, this unit has a large 12mm display and is fitted with life time lithium batteries.

Model UR2000 (exclusive to Solex), has a three mode display which allows conversions from metric to imperial or vice versa using the mode function. The unit is also fitted with a memory recall button which allows the last measurement to be recalled even after the unit has been switched off, for any length of time. Three year life replaceable lithium batteries are supplied as standard.

Model UR3000, (exclusive to Solex), is a world first in Ultrasonic Measurement Technology. UR3000 is one of the first models available to offer an advanced array of features at such an economic price. Additional features to the UR2000 include (1) length, width and height readings automatically stored in independent memories (2) Square function and (3) cube function. Digital UR3000 is another advanced innovative product available only from Solex.

IDEAL FOR SURVEYORS, ENGINEERS, BUILDERS, ESTATE AGENTS, PROFESSIONALS, D.I.Y. ENTHUSIASTS, etc., etc.

SELECTIONS FROM THE SOLEX RANGE

SELECTIONS FROM THE SOLEX RANGE

PRICE	UR1000	1-4 (QTY)	5+ (QTY)
		£22.00	£19.00

PRICE	UR2000	1-4 (QTY)	5+ (QTY)
		£29.00	£26.00

PRICE	UR3000	1-4 (QTY)	5+ (QTY)
		£49.00	£44.00

UR1000 FEATURES/SPECIFICATIONS

- Range 50 centimetres — 10 metres
- Reading in metres and centimetres
- Built in 3V life-time lithium batteries
- Accuracy better than 1% of the reading
- Resolution: 1 centimetre
- 12mm liquid crystal display
- Error indication
- The unit is temperature compensated
- Automatic — shut off
- Size: 65mm × 128mm × 22mm
- Weight: 100g
- Finished in a superb matt black ABS case

UR2000/UR3000 FEATURES/SPECIFICATIONS

- Range 60cm - 10 metres.
- Accuracy better than 1% of the reading.
- 3 mode display: Metric, Imperial and Imperial/Metric
- Memory recall: Last measurement stored in the memory even in off mode.
- Hold: Automatic hold of reading for 10 seconds.
- Shut off: Automatic, 10 seconds after last entry.
- Power source: 3 year life, replaceable lithium battery.
- Audible feedback: Beeper tone indicates measurement complete.
- Error indication.
- Automatic temperature compensation: From 0°C to 40°C.
- Size: 65mm × 128mm × 22mm.
- Weight: 100g.
- Finish: Matt Black ABS.

UR3000 ADDITIONAL FEATURES

- Length, Width, Height: readings automatically stored in independent memories.
- Square function: calculated automatically from length and width to give floor area.
- Cube function: calculated automatically from length, width and height to give capacity of room.

ALL SOLEX'S DIGITAL TAPES WORK WITH A LOW BEAM ANGLE OF 8° - 7° AND INCORPORATE ULTRASONIC POLAROID SENSORS

AVAILABLE ON FREE 14 DAYS APPROVAL

PRICE BREAKTHROUGH

☎ TELEPHONE YOUR ORDER THROUGH TODAY FOR IMMEDIATE ATTENTION.
(AUTOMATIC COMPANY ACCOUNT FACILITIES)
0455-283486

SOLEX

Solex's full colour test and measurement catalogue is now available. Phone for your free copy.

25 × 10

T2/2

Ultra sonic measurement

NEW from Luft Industries (Pty) Ltd is the SupaRule sonic tape measure.

The SupaRule features automatic temperature compensation together with a narrow beam angle of 6°C, to produce an instrument with exceptional accuracy (better than 99,95 %) over a wide measuring range (0,271 m to 25 m).

Other standard functions include metric/imperial conversion, three levels of memory for area and volume calculations, constant display of ambient temperature and sequential addition of measurements.

SupaRule's state-of-the-art technology ensures highly reliable, thermally compensated measurements to a high degree of accuracy. The portability and ease of operation even in semi-cluttered environments will be of

The SupaRule ensures highly reliable, thermally compensated measurements.

Precision tape for fast measurement

A HANDHELD precision measuring tape to measure, calculate and store lengths, area and volume, is now available from Timecount.

Measurement is carried out via an ultrasonic sensor which beams out a signal from one wall to another. The unit is ideally suited for a wide variety of users such as architects, builders, floor layers, tilers, electricians, interior designers, masons and carpenters.

The tape adds and subtracts. All functions are via a simple-to-operate keypad which allows for three separate length measurement inputs and an area and volume calculation. Information can be stored in memory if required.

Measuring range is from 0,6 to 14 m.

Distance estimator

A new ultrasonic distance estimator from Polaroid has been launched in South Africa by Toplan Design and Marketing. It is powered by a lithium battery with a life estimation of 10 years and an accuracy factor of 99 % at 9,14 m.

The product, which is aimed at building professionals, DIY enthusiasts, and tradesmen, carries a 12-month unconditional guarantee.

Toplan Design & Marketing, PO Box 65302 Benmore 2010 (phone: (011) 783-7250)

Pointing to the trouble

WHAT builder or engineer visiting a construction site has not, at some time, pointed out a structural defect, for example perhaps four storeys up, to a contractor, colleague or client at the daily site meeting?

Then, finding he is unable to make the exact spot clear to them, has had to accompany them all the way up the ladder to show them, wasting valuable time?

The Swiss have developed a product that saves everybody's time - a pocket laser fitted with the latest laser diode technology which can highlight features of a building with pin-point accuracy over a distance of up to 200 m.

Totally new to SA, it is being marketed by the Hass group.

The laser pointer can also be used in training, education, boardrooms and lecture halls. (012) 731016

T2/3

NEW! SOLEX DIGITAL ULTRASONIC TAPE UR4000

ACCURACY BETTER THAN 99.9%. WIDE MEASURING RANGE 271mm to 25 METRES. NARROW BEAM ANGLE OF 6°. AREA AND VOLUME CALCULATIONS. SEQUENTIAL ADDITION OPERATION. METRIC/IMPERIAL CONVERSION. TEMPERATURE DISPLAY. THREE SEPERATE MEMORY BANKS. LOW BATTERY AND POOR TARGET INDICATOR. HIGH RESOLUTION TO MILLIMETERES AND EIGHTHS OF AN INCH. AUTOMATIC TEMPERATURE COMPENSATION.

ADVANCED ACCURACY AND PERFORMANCE

Solex are now able to offer the Ur4000 distance meter, a further addition to their extensive Ultrasonic Tape Measure range. Solex has fast become the UK's leading supplier of low cost ultrasonic measuring equipment and the addition of the UR4000 further strengthens our position.

Solex's UR4000 is packed with outstanding features and is one of the most accurate ultrasonic tape measures on the market today with accuracy being better than 99.9%. The unit measures over a distance of 271mm to 25 metres and combines a narrow beam angle of 6°. Temperature compensation is standard.

Solex's UR 4000 is the only Ultrasonic Tape Measure to display measurements to millimetres and eighths of an inch. Area and volume calucation facilities and sequential addition operation are also standard to the unit.

A memory system holds and stores linear measurement's in three seperate memory banks. Further unique features of the unit include Temperature, Poor Target, and Low Battery indications.

Solex's UR4000 is manufactured in the U.K. to exacting standards and comes supplied with a full two year guarantee.

SOLEX – ALWAYS AHEAD IN ULTRASONIC TAPE MEASUREMENT

- **UR4000 FEATURES/SPECIFICATIONS**
- Range: 271mm to 25 metres
- Accuracy: Better than 99.95% to ± 1 digit
- Resolution (metric): 0.271 to 2.999 metres 1mm
  3.00 to 9.95 metres 5mm
  10.00 metres and over 1cm
- Resolution (imperial): ⅛th inch (min.)
- Three independent separate memory banks
- Metric/Imperial conversion button.
- Automatic Temperature compensation from 0° to 35°C
- Atmospheric Temperature is continuously displayed
- Beam Angle: 6°
- Automatic Shut Off after three minutes
- Area and Volume Calculation facilities
- Sequential addition operation.
- Automatic low voltage indicator
- Poor target and overrange indicator
- Power: Measuring 135mW
  Standby 45mW
- Battery: PP3 (supplied)
- Size: 195 × 77 × 58mm
- Finish: High Gloss ABS casing

TWO YEAR GUARANTEE

PRICE	UR-4000	1&4 (QTY)	5+ (QTY)
		£99.00	£94.00

AVAILABLE ON 14 DAYS FREE APPROVAL

SELECTIONS FROM THE SOLEX RANGE

SOAR DIGITAL LEVEL METER MODEL L1700

DIGITAL DISPLAY OF ANGLE AND GRADIENT. 0·5° RESOLUTION. REPLACES PRECISION LEVELS. INCLINOMETERS. ANGLE BLOCKS, AND SINE PLATES WITHOUT ANY SET UP TIME

Digital display of angle and gradient. 0·5° resolution.
Replaces precision levels, inclinometers, angle blocks and sine plates without any set up time.

Soar's digital level meter model no. 1700 is now the new efficient solution for the measurement of angle and gradients to a high degree of accuracy. This revolutionary instrument gives an easy answer to all your angle and gradient problems, eliminating the need for tedious set-up time and guess work. The first time you place a Soar level-meter on a surface, you will discover efficiency that was never possible until now. It puts every measurable angle within your grasp.

FEATURES

- Accurate digital level measurement with an accuracy of 0·5° over the wide range of ± 120°.
- A beeper may be sounded at the 0° (horizontal) position to enable audible verification of this condition.
- Measurement of both "angle" and "grade".
- Individual annunciators indicate an increasing or decreasing slope.
- A display hold switch may be used to freeze the display value, a convenient feature for taking measurements in locations which prevent the display from being read directly.
- Two liquid crystal displays (top and front) enable observation from virtually any angle.
- A lamp may be switched on for night time use.
- An automatic power cut off circuit switches the unit off if no measurements or other operations are made for three minutes or longer, thus saving battery life.
- Two type AA batteries enable operation for approximately 50 hours.
- The use of photoelectric sensing ensures freedom from the effects of electro magnetic fields and provides stable operation over long periods.

PRICE	L1700	1-4 (QTY)	5 + (QTY)
		£79.50	£74.50

300mm BASE + £21.50	600mm BASE + £32.00
450mm BASE + £26.50	1000mm BASE + £42.50

SELECTIONS FROM THE SOLEX RANGE

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You may order on the telephone or by post. Your requirements, if sent by post, should be on official authority, requisition, letterhead or similar authorised material. Orders are welcome from establishments/businesses who have not dealt with us before and provided the order value is below £500, we accept and despatch your order immediately.

All goods are then invoiced on a strictly 30 day net basis. All orders are subject to £2 carriage and VAT. Should you wish to order by telephone please ensure that any written orders sent by post to confirm the details of your order are clearly marked 'confirmation only'.

All good supplied by Solex are available on 14 days approval. If at the end of this period you are not satisfied, just return the item/s to us without any further commitment to yourselves.

Solex endeavour to despatch all orders within 48 hours, however this is not always possible or in fact feasible. If we cannot supply any or part of your order, we will inform and acknowledge within 24 hours.

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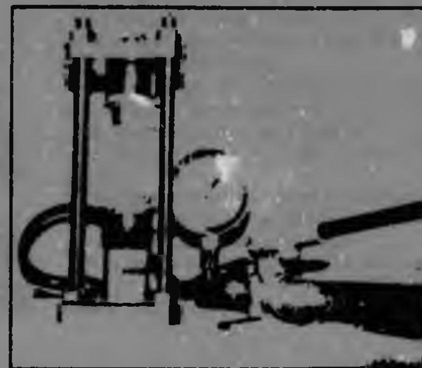
T3/1

Below we have briefly detailed some instrumentation availabie from Terra Monitoring. However, our services have expanded since our inception in 1980 to include local design and custom manufactured items for use in the mining, geotechnical and civil sectors.

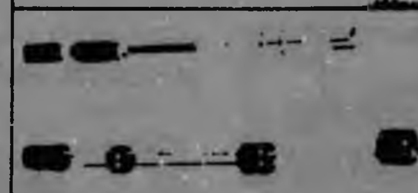
Our services have broadened to offer a comprehensive field testing capability and assistance with installation and monitoring of installed instrumentation.

◄ TAPE EXTENSOMETER: Fast, accurate readings; measures small changes in distance between two points up to 30m apart; for use in monitoring of underground openings subject to changing ground stress.



ATKINSONS UNIAXIAL FIXED UNIT: Used for direct determination of uniaxial strength in the field; portable loading frame, quick results at low unit cost. ►

◄ STRESSMETER. Read borehole stress change directly at up to 3 positions, intrinsically safe; robust unit with excellent long term stability

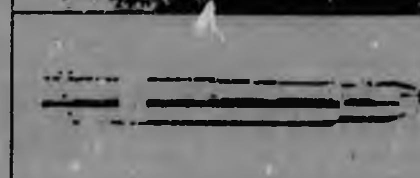


MULTIPOINT ROD EXTENSOMETER: Reliable and accurate measurement of linear deformation. Applications include slopes, tunnels, dams, piles, foundations, etc ►

◄ SONIC PROBE EXTENSOMETERS Accurate, high resolution unit for monitoring of roof bed separation and crack development Intrinsically safe

HYDRAULIC PRESSURE CELLS Available for either pneumatic or oil hydraulic operation, for measuring of backfill, joint pressure, concrete pressure and rock stress in boreholes ►

◄ CSIRO HOLLOW INCLUSION STRESS CELLS Provides a method of determining the three-dimensional stress state in rock based on the overcoring principle. Reliable device with good success rates

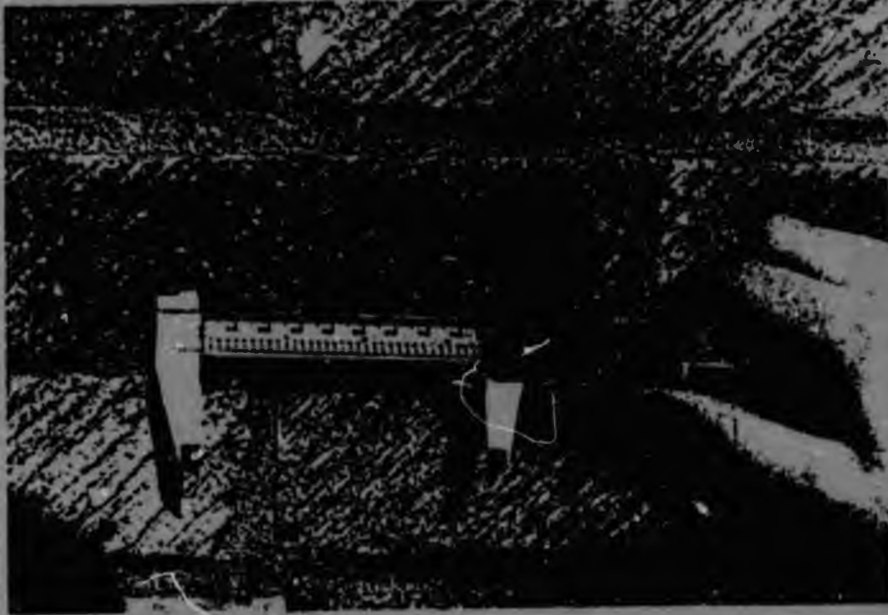


BOREHOLE DEFORMATION GAUGE: The gauges are rugged, highly sensitive and stable. Latest USBM design to be used with overcoring method for measurement of in situ stresses in rock ►

TERRA MONITORING

Geotechnical civil and mining instrumentation

5th Floor, Braamfontein Centre, Braamfontein 2001. PO Box 31600, Braamfontein 2017.
Tel: (011) 339-2468/9. Telex: 4-24858



Crack monitoring

TB/2

Avongard is now marketing the digital electronic caliper crack monitoring system.

Accurate to 0·01 mm the digital caliper compliments the established Avongard dial and vernier crack monitoring system which has proved so useful to those involved in investigating damaged buildings and civil engineering structures.

Supplied complete with a quantity of 6·3 mm diameter stainless steel monitoring discs, which are adhered to the wall each side of the crack, the calipers can be used to make quick and accurate readings of the opening and closing of the crack.

As an alternative to the discs, brass screws and rawlplugs are supplied. These perform the same function as the discs, acting as a reference point for the caliper when taking readings.

The system can be used internally or externally, and crack monitoring record charts are provided with the instrument.

Full details can be obtained from Avongard Ltd., 61 Down Road, Portishead, Bristol BS20 8BR (☎ 0272 849 782).

DID IT MOVE, OR DIDN'T IT?

Our automated deformation-sensing systems give you the graphic answer!

Now, continuously monitor the tilts, bulges, bends and deformations of:
• Bridges • Buildings • Stadium Roofs • Dams • Tanks • Tunnels • Slopes • Any Other Structure

Versatile and singularly precise, our field-proven systems are your best choice for testing, inspection or long-term surveillance.

APPLIED GEOMECHANICS

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Phone (408) 462-2801 — Fax (408) 462-4418

Simple and Affordable Movement Monitoring

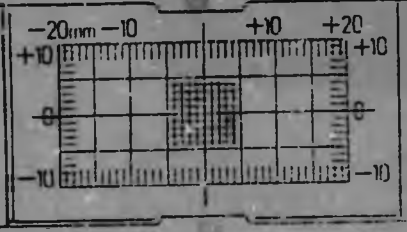
METRUM Monitoring Systems continuously measure and record non-seismic crack and joint displacements in buildings, bridges, parking structures, etc. At last, actual data supports design, maintenance and investigation. Features include:

- Date, time, displacement and temperature recording
- Portable system moves from project to project
- Easy to install and operate -- no computer experience needed
- Small, durable, weather-resistant and built to last
- Affordable and accurate
- Simple, easy to understand tabular and graphical output

METRUM CORPORATION

165 South Union Boulevard, Suite 855, Lakewood, CO 80228
Fax: 303-986-1232 Telephone: 303-986-6210

TB/3



CRACK
MONITORING
EQUIPMENT

AVONGARD™

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Bristol BS20 8RB
Telephone 0275 849782
Facsimile 0275 848062

OUR NEW TELEPHONE NUMBER:
0275 849782

TB

The strain gauge, just one of the different types of sensors we measure movement, temperature, deformation, crack growth – in fact all necessary parameters for effective structural integrity assessment.

The installation of sensors is a science, and one which Strainstall have perfected with special installation techniques and experience built on working worldwide on everything from huge dams to simple footbridges.

The data we produce so cost effectively is relevant data. Our data-logging techniques are refined by combination of years of experience in the management of sophisticated equipment and developing our own systems.

Using Strainstall means carefully considered placement of the correct sensor, the appropriate degree of testing, and as a result no generation of the infamous, impossible to climb, Data Mountain.

As many professionals already know, structural analysis services from Strainstall count for a great deal. Call us with your requirement.

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ENGINEERING SERVICES
COWES BATH TONSBERG

Strainstall Engineering Services Limited

Denmark Road, Cowes, Isle of Wight PO31 7TB Tel. 0983 295111 Fax. 0983 291335
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RAYTEK Inc has introduced a new model, the PMSZ, in its line of hand-held infra-red thermometers. It measures temperatures from −45 °C to +400 °C, and displays both the instantaneous temperature as well as the maximum temperature. The display, which is updated four times a second, is accurate to ± 1 % of reading and repeatable to ± 0,5 % of reading.

The PMSZ measures a 12 mm spot size up to 0,5 m away from the object and as one moves farther away the spot size increases to 300 mm at about 7 m. This is particularly beneficial where mechanical or electrical systems may be hazardous to touch or difficult to access and in freezers and coolers where the sub-zero temperatures

The PMSZ measures a 12 mm spot size up to 95 m away.

affect the stability of conventional thermometers.

The PM series of infra-red thermometers contains advanced optical and electronic systems, but they are simple to use and

Temp indicator transducer

A new digital indicator provides the link between temperature sensors and higher level process instrumentation.

The design places emphasis on operator friendliness, ease of commissioning and fault finding.

The 96 by 48mm Diger offers a host of features including: 4..20mA temperature retransmission, loop current sourcing and sinking, front adjustable temperature display, sensor fault detection and thermocouple reverse polarity detection.

All controls are hidden behind the faceplate, preventing unwanted tampering with the settings after commissioning.

The unit is also available as a plain indicator.

ENQ: Richard Mayr (021) 73 1016 or circle No 207 on the enquiry coupon on page 37.

APPENDIX D : CASE STUDIES

R E P O R T

NEWTOWN REDEVELOPMENT SCHEME

THE TURBINE HALL - AUGUST 1989

INTRODUCTION:

This Report comprises an investigation into the existing building structure of the Turbine Hall and is sub-divided into the following sections:-

Section 1. "As built" drawings of the existing building drawn on A0 sheets which have been reduced to A2 and are separately bound into a single document accompanying this Report. (Refer Report No. 4 of 5). The drawings should be referenced together with this Report.

Section 2. State of Condition Survey.

Section 3. Materials Report.

Section 4. Structural Analysis.

Section 5. Conclusions.

SIGNED: .... DATE: 31-8-89.......

REPORT

NEWTOWN REDEVELOPMENT SCHEME

MATERIALS REPORT - MARCH 1989

This report details the results of material tests and inspection of the various structural materials used in the construction of the Turbine Hall, forming part of the Newtown Redevelopment scheme.

1. **BRIEF:**

   The brief as indicated by Mr. R. Finkelstein of the Johannesburg City Engineer's Department, was to assess the strength of the concrete work in the various buildings as well as to comment on the degree of deterioration and corrosion to the structural steelwork, reinforcement and brickwork where this occurred.

2. **PRESENT AT INSPECTION:**

   The inspection and coring was carried out and supervised by our Mr. R.E. Baker during March 1989. The various tests on the concrete were conducted by the Portland Cement Institute at Halfway House.

2/...

3. TURBINE HALL:

3.1 Concrete Work:

3.1.1 This is a reinforced concrete portal framed building and all tests carried out were related to the strength and durability of the in situ concrete.

3.1.2 Six concrete cores were taken (see positions on attached drawing No. 77/23/56/18 of various structural elements of the building and tested at the Portland Cement Institute for compressive strength and a cement: Aggregate ratio test was carried out on core Nos. TC11 and TC5. The results of these tests can be seen on the attached reports from the Portland Cement Institute dated the 17/3/89 and 23/3/89 respectively.

3.1.3 A series of Schmidt Hammer tests were carried out. (See positions indicated on Drawing Nos. 77/23/56/18 and 77/23/56/19 attached) using the results of the core tests taken previously (see Item 3.1.2 above) as a calibration for the results obtained. The results of these tests are listed below:-

SCHMIDT HAMMER TESTS - 6/9/89

TURBINE HALL

CORE TEST NO.	S. HAMMER TESTS	REBOUND READINGS	REBOUND AV	CUBE COMP. STR (MPA)	CORE. STR. MPA
	SH1	24, 30, (19), 34, 40, 38, 32, 32, (42), 40, 38, 32	34	44	
	SH2	(30), 40, (42), 34, 38, 32, 34, 36, 32, 30, 34, 38	35	46	
	SH3	36, 38, 38, 44, 42, (46), 40, 42, 42, (32), 36, 40	40	55	
	SH4	34, 34, 32, 34, (30), 34, 32, 30, 36, 32, 36, (38)	33	42	
	SH5	(24), 36, 32, 34, 30, 28, 32, 28, 34, (38), 28, 28	31	38	
TC1	SH6	40, 40, 38, 38, 40, 42, 38, 42, 40, (30), (44), 38	40	55	16,5
	SH7	40, 38, 38, 34, 38, (32), 32, 40, 38, 34, (42), 40	37	49	
	SH8	28, 32, 36, (38), 32, 38, 38, 34, 36, 30, 32, (24)	34	44	
	SH9	38, 40, (34), 40, 42, (48), 34, 40, 40, 38, 40, 34	39	53	
	SH10	40, (42), 40, 40, 40, (38), 40, 40, 38, 42, 42, 40	40	55	
	SH11	42, 38, 42, 40, (34), 42, 38, (44), 42, 36, 40, 44	40	55	
	SH12	36, 34, (38), 34, 38, 36, 34, (30), 36, 32, 38, 34	35	45	
	SH13	40, (42), 40, 38, 40, (36), 38, 38, 38, 38, 40, 40	39	53	
	SH14	(40), 34, (32), 40, 36, 38, 38, 36, 34, 36, 36, 36	36	47	
	SH15	50, (54), 50, 52, (48), 48, 50, 52, 52, 50, 50, 52	51	>60	
TS2	SH16	(38), 42, 42, (44), 44, 42, 40, 38, 40, 40, 40, 42	41	49	26
	SH17	32, 32, (30), 32, 32, 30, 30, 32, 30, 30, (34), 30	31	38	
	SH18	30, (34), 34, 32, 34, 30, 34, 34, 32, 30, (28), 32	32	40	
	SH19	30, 32, 32, 30, (34), 32, 34, 32, 32, 34, 32, (28)	32	40	
	SH20	34, 40, 36, 36, 40, 40, (32), 34, 38, 40, (42), 38	38	51	
TC6	SH21	48, 48, (36), 38, 40, 44, 38, 38, 40, 44, 44, (50)	42	58	35
	SH22	42, (38), 44, 44, 44, 44, 42, 48, 48, 46, (50), 52	45	>60	
	SH23	(34), 38, 38, 36, (40), 40, 36, 38, 40, 36, 34, 34	37	49	
TC5	SH24	(40), 42, (44), 44, 42, 44, 44, 42, 40, 40, 40, 40	42	58	25
	SH25	42, (40), 42, 42, 44, (46), 44, 40, 44, 40, 42, 42,	42	58	
	SH26	(42), 44, 50, 50, 50, 46, 44, 48, 48, (52), 50, 44	47	>60	
	SH27	40, 42, 38, 40, 38, (32), 38, 40, (44), 44, 38, 40	40	55	
TS3	SH28	(32), 38, 36, 38, 38, 40, 40, 38, 40, 38, (42), 40	38	51	35
	SH29	34, (32), (42), 38, 40, 38, 38, 38, 34, 36, 34, 36	37	49	
	SH30	(38), 44, (46), 42, 44, 40, 44, 40, 4), 42, 40, 42	42	58	
	SH31	40, (42), 40, 40, 38, 42, 40, 38, 40, 38, (34), 42	40	55	
	SH32	44, 44, (50), 48, 44, (28), 40, 44, 48, 40, 42, 44	44	64	
	SH33	42, 42, (48), (40), 42, 44, 42, 40, 44, 44, 46, 44	43	>60	
	SH34	38, 34, 38, 38, 36, 34, 32, (30), 34, 34, (42), 36	35	46	
	SH35	38, (30), 38, 32, 34, 40, 36, (40), 36, 34, 36, 40	36	47	
	SH36	42, 38, (32), 34, 42, 40, 40, 38, 44, 42, 42, (48)	40	55	
	SH37	44, 42, 38, 38, 40, (32), 34, (50), 32, 34, 46, 42	39	53	
	SH38	38, 42, 42, 40, 44, 38, 38, (38), 44, (48), 46, 46	42	58	
	SH39	40, 40, (50), 42, 40, (30), 44, 40, 44, 38, 42, 40	41	57	
	SH40	32, 30, 30, 30, 30, 30, 30, 30, (34), (28), 30, 32	30	37	

4/...

3.1.4 Seven further cores (T1-T7) were taken (see positions on Drg. Nos. 77/23/56/18 and 77/23/56/19) in order to determine the extent of carbonation that had occurred in the concrete. The results of these tests may be seen on attached report from the Portland Cement Institute dated 29/3/89. Further information on carbonation may be obtained from Fulton's Concrete Technology (Sixth Revised Edition 1986) Chapter 8, as prepared by the Portland Cement Institute at Midrand. (See photo Nos. 1 - 6 taken in laboratory attached).

4. CONCLUSIONS:

4.1 Reinforced Concrete Work

There is generally no correlation between Schmidt hammer test and core crushing tests. Both, however, indicated a wide spectrum of strength results.

Evaluation of concrete strengths in the elements of any particular building will have to be done in due course by means of core testing and statistical analysis.

Cement content tests indicate generally that the concretes provided are "lean".

Carbonation tests indicate that all concrete work suffers from carbonation to significant depth. Accordingly concrete work generally will have to be suitably surface treated to prevent the onset of reinforcement corrosion.

In areas corrosion and spalling has already occurred and repairs will be necessary.

SIGNED: ....*L. E. Baker*.......... DATE: ....*31.8.79*........

A. REINFORCED CONCRETE COLUMN

1.0. COMMENTS ON TEST RESULTS AND PHYSICAL INSPECTIONS

The cover to the column reinforcement is the highest of the three members investigated, but is still low, considering that the column is externally exposed to the weather and the industrial atmosphere.
However, the important factor is that the carbonation depth varies between 30 and 35mm which is greater than the cover.
The rust staining visible on the external face verifies that the reinforcement is corroded, and it is this corrosion which has resulted in the large cracks and spalling of the concrete.

The low pH of the concrete is related to the large carbonation depth. Carbonation reduces the concrete pH and is the basis of the carbonation test using a phenolphthalein solution.

The chlorine content of 0,26%; alkali content of 3,7kg/m³ and short term free-swell expansion of the core sample of 520 $\mu\varepsilon$ are all within acceptable limits and are indicative that these three factors are not major contributors to be noted defects and deterioration of the column.

2.0. THE CAUSES OF THE OBSERVED DEFECTS

2.1. PRIMARY CAUSE
The primary cause of the cracking and spalling concrete is the carbonation of the concrete for the full cover depth and beyond. Associated with the carbonation is the reduction of pH of the concrete, thus resulting in reinforcement corrosion in the presence of oxygen. Carbonation changes the crystal structure of the cement in the concrete, which increases in volume and thus results in spalling of the outer layers of the member.

2.2. SECONDARY CAUSE

The secondary cause in this case is initiated by primary cause, water and pollution effects cause accelerated reinforcement corrosion. The large cracks (0,7 - 1,5mm) caused by the spalling, provide little opposition to water ingress on the external face. As 1mm of steel reinforcement yields 10mm of rust on the surface, the internal volume increase continues, thus causing more spalling of the concrete.
This form of material deterioration is not an alternative to the primary cause, but as a result of the primary cause.

3.0. STRUCTURAL IMPLICATIONS

The structural implications of the cracked and spalled concrete and the corroded reinforcement can only be assessed on closer inspection and by calculations of stresses, knowing the approximate future loads, and the concrete areas capable of functioning in compression.

From the photographs (see appendix) it would appear that the concrete at the top of the column is more badly cracked than at the bottom. The loads, however, are also lower near the top, so calculations may indicate that the current situation is acceptable and the concrete should only be protected against further deterioration.

The corrosion extent must be examined by exposing the reinforcement and the implications assessed.

4.0. EFFECT ON MATERIAL DURABILITY

Both the carbonation and water ingress have severely impaired the durability of the column concrete and will continue to do so at an accelerated rate as more water and pollution is able to attack the reinforcement. From the photographs, it would appear that the concrete near the top of the column may crumble away completely in the future, if not protected.

5.0. REMEDIAL MEASURES

When the structural implications have been more accurately assessed, the exact extent of the remedial measures will be evident.

Judging from the photographs, it seems that the following measures would be most appropriate:

a. Removal of all cracked and spalled concrete.
b. Grit blasting of the reinforcement to remove all rust.
c. Removal of all loose material before applying a bonding agent to the roughened surface.
d. Casting fresh concrete within partial framework in the regions previously spalled.

The visual inspection highlighted that crack repairs had been performed previously, but it isn't clear if they have been successful or not. If the repairs show signs of deterioration then the area should be treated in the way outlined above.

If, during the grit blasting, it becomes clear that a large cross-section of the reinforcement has corroded for a significant length, the situation must be re-assessed as large scale reinforcement replacement is rarely practical.

Portland Cement Institute — Portlandsementinstituut

(Incorporated association not for gain) — Reg. No. 05/11756/08 — (Ingelyfde vereniging sonder winsoogmerk)

South Africa — Suid-Afrika

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101, Tshiawelo 1818	Soweto		(011) 984-4056/7

Please reply to Antwoord asseblief aan: H/O FAX No.315-0300 Ext 200 (Office Hours)
Head Office

Lab.Ref: CL.186/89/AS/JAF — Date: 23 March 1989

Client: Kampel Abramowitz Yawitch & Partners

LABORATORY REPORT

Four concrete cores were submitted and we were requested to test for the cement:aggregate ratio.

Test	Method	Sample no	Result
Cement:aggregate ratio	BS 1881: Pt 124	BF 1	1:7
		TC II	1:7
		TC 5	1:6
		WW I	1:9

The results are reported by mass on a loss free basis.

The assumption is made that there is no calcium present other than that in the cement and that the cement contains 64 % calcium oxide.

This laboratory report relates only to the specimens tested.

A SETLOGELO
for Executive Director

Executive Committee/Uitvoerende Komitee — I.G. Pretorius (Chairman/Voorsitter), D.W. Bain, E.C. Cockcroft, T.G. Coulson, M.M. Doyle, J.E. Hodgkiss, G.R. Luyt, H.F.C. Searle
Executive Director/Uitvoerende Direkteur — S.W. Norton Pr. Eng.

Portland Cement Institute — Portlandsementinstituut

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13019, Humewood, 6013	Port Elizabeth		(041) 53-2141
101, Tshiawelo, 1818	Soweto		(011) 984-4056/7

Please reply to Antwoord asseblief aan

Head Office
HO Fax No. 315-0300 ext 200 (office hours)

Lab.Ref. 186/89/BJA/JAF

29 March 1989

Kampel Abramowitz Yawitch & Partners
PO Box 5076
JOHANNESBURG
2000

Attention: Mr Ross Baker

Dear Sirs

NEWTON REDEVELOPMENT PROJECT: CARBONATION OF CONCRETE

Tests were carried out in our laboratory to determine carbonation depths of concrete cores supplied by you and taken from the above. Results were as follows:

Specimen mark	Depth of carbonation (mm)
B1	45 to square end, 35 to skew end
B2	25 to white face, 40 to black face
W1	110 to 140
W2	Carbonated right through except for isolated spots
W3	20 to 60 outside face
T1	10 inside face, 40 outside face
T2	70 rough face, 5 painted face
T3(a)	50
T3(b)	50 inside face, 30 to 50 outside face
T4	10
T5	5 inside face, 20 outside face
T6	Carbonated right through
T7	35 inside face, 30 outside face

Executive Committee/Uitvoerende Komitee — J G Pretorius (Chairman/Voorsitter), D W Bath, E C Cockcroft, T G Coulson, M M Doyle, J E Hodgkiss, G R Luyt, R F C Searle
Executive Director/Uitvoerende Direkteur — S W Norton Pr Eng

Lab.Ref. 186/89/BJA/JAF 29 March 1989

Kampel Abramowitz Yawitch & Partners

Carbonation occurs when the calcium hydroxide in cement paste is converted to calcium carbonate by carbon dioxide from the air:

$$Ca(OH)_2 + CO_2 \longrightarrow CaCO_3 + H_2O$$

The significance of carbonation is that the pH of the paste is reduced to a level at which the paste is unable to protect reinforcement from corrosion. Steel in carbonated concrete is therefore vulnerable to corrosion.

Yours faithfully

B J ADDIS Pr Eng
for Executive Director

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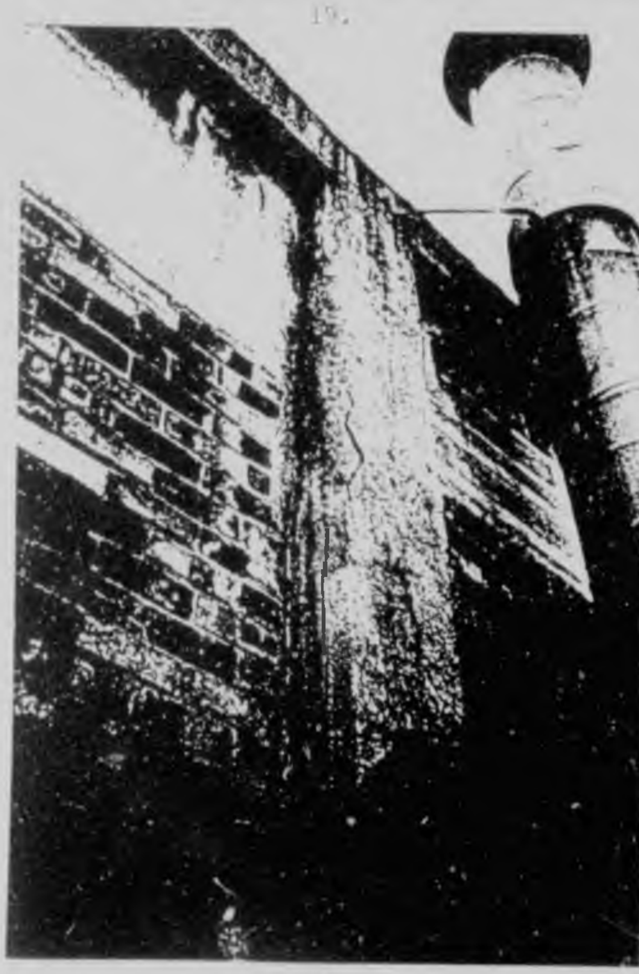

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Author Finkelstein R S
Name of thesis A systematic method for the appraisal and renovation of existing structures 1993

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