Return to previous file: Part 3

and bodies who may offer funding assistance and grants for conservation work. This will ensure that all parties have been consulted and the best possible options have been explored within the parameters and resources available. Ideally, the specialists and consultants involved in the analysis should continue their contribution by helping to determine conservation strategies together with the owner or those managing the structure.

8.2 CONSERVATION STRATEGIES

The criteria for what constitutes an acceptable repair for a historic structure will often differ from those for a modern structure. Appropriate strategies will be guided by sound structural practice, sound conservation principles and a thorough analysis of the existing structure (Fig. 23).

For conservation purposes, the first option to be considered is a policy of preservation and minimum intervention that ensures the best long-term survival of the structure whilst at the same time retaining its heritage attributes. The best way to achieve this is to find an appropriate balance between preservation of original material and the addition of necessary new material to ensure the continued safety of the structure. When deciding what action should be taken, there should, therefore, be consideration of the retention and protection of the existing fabric.

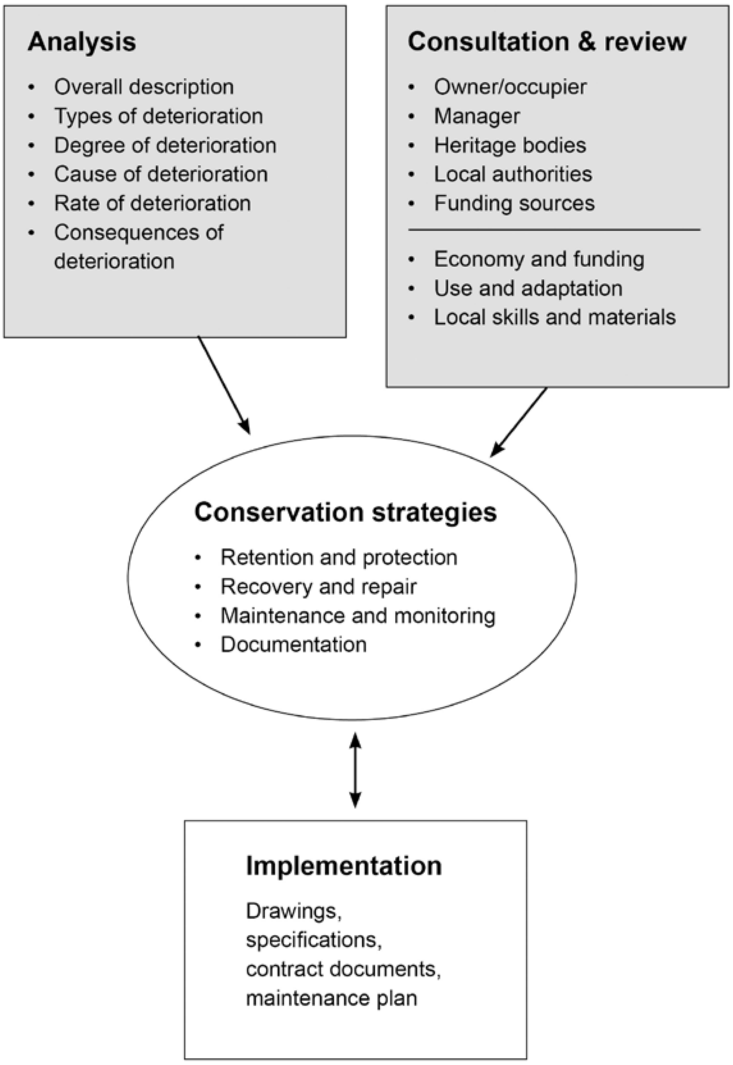

Figure 23. Determining conservation strategies for concrete buildings.

The next step is to consider whether recovery of parts of the structure is appropriate and what repairs should be undertaken, depending on resources available. In all instances, the aim should be to find the best possible way to do this without compromising the heritage value of the structure.

Finally, any work that is undertaken should be documented for future reference and for establishing an ongoing process of maintaining and monitoring the structure. Working through the following strategies during the process of consultation and review will help to determine what action will be the most appropriate in each case.

8.2.1 Strategy 1—Retention and protection

Any intervention should aim to retain cultural and historic significance of the structure through the necessary process of repair. For a historic building or structure, this may mean that what is new should be distinguishable from what is original. Stabilisation, risk mitigation, adaptation and interpretation may be involved in retention and protection of fabric.

Stabilisation

Where necessary, stabilisation of the structure is the first and most basic step to ensure its future survival. Preventing, arresting and slowing further decay can be achieved by removing the cause of deterioration, where possible, and by treating the existing fabric to slow or minimise further deterioration.

Sometimes a simple support can prevent further deterioration of a structure and ensure that it is safe. Such support should be reversible, so that a complete process of repair can be undertaken when and if this is possible or appropriate.

Risk mitigation

Any risks to the structure or that may be caused by the structure should be identified and appropriate steps taken to mitigate their effects. Damage to the structure could be from natural or other events, e.g. fire, graffiti, farm animals, over-use or plant invasion. Unsafe aspects of the structure could include loose material that could fall, and cavities or unprotected openings in which children or animals could be hurt. Each situation will require its own risk evaluation and action, e.g. fencing or covering the structure. Again, such measures should be reversible.

Adaptation

The likelihood of future protection of the structure can be greatly improved by ensuring that it fulfills a useful purpose. This can be social, cultural or economic. In some instances, adaptation of the structure may be necessary to achieve this. If additions are needed to adapt a structure, it should be clear what is new and what is original, while remaining sympathetic to the existing structure.

Interpretation

Interpretation of a place can increase public understanding and ensure that the structure is better protected. This can include brochures describing the structure and its background, signboards on the site, articles in local newspapers, or listings on historic site lists advertised by the New Zealand Historic Places Trust or the Department of Conservation.

8.2.2 Strategy 2—Recovery and repair

Where resources allow, recovery and repair of the structure is recommended to promote its long-term survival while maintaining its heritage value. Any intervention should aim to recover cultural and historic significance. Again, a policy of minimum intervention is recommended. In some instances, reconstruction of fabric may be appropriate. Several processes may be involved in restoring the structure to an earlier state, including removal of accretions, repair, reinstatement and reconstruction.

Removal of accretions

In some instances, structures may have had unsympathetic additions or fabric added that detract from the heritage value of the structure or may even be causing damage. Where possible, these should be removed and any affected fabric repaired or reinstated. Not all additions should, however, be regarded as accretions; if they add to the heritage value of the structure, they should be maintained. Where unsympathetic accretions are necessary and perform a useful function but detract from the heritage value, consideration should be given to their replacement with a more compatible solution.

Repair

It is not possible to draw up a simple table of materials and methods to cover all the situations that may be encountered during the repair of a concrete structure, and broad generalisations will propagate incorrect information. In every case, the selection of appropriate materials and methods should be with reference to the original materials used in the structure. Suitability for purpose must always be the aim.

In conservation, it is generally preferable to find materials that match the original in porosity, hardness and colour. The new material should be sacrificial to the original material rather than stronger than it, to avoid it causing further deterioration of the original material.

Techniques for repairing historic concrete structures have advanced greatly in recent years. Modern techniques can be based on the use of non-cementitious materials acting as *bonding mediums*, chemical binders, strengtheners, consolidants, and admixtures such as plasticisers. These materials primarily provide effective structural repair quickly; aesthetic considerations are secondary. Because such techniques are relatively new and have not been the subject of long-term experimentation and evaluation, common sense and compromise should be used when selecting a technique and deciding on the extent of work. Test all techniques and mixes before carrying out a repair.

Before selecting a repair method:

- Consider the performance required of the repair
- Bear in mind that repaired concrete may not be as sound as a monolithic mass of concrete

- Remember that in all repairs shrinkage must be minimised, compatible materials must be used and workmanship must be of the highest standard
- Consider a policy of non-intervention, monitoring, preventive maintenance and judicious neglect

Reinstatement

Items and fabric that have been displaced should be restored to their original position with the least additional material or intervention possible while still ensuring that the structure is sound and safe.

Reconstruction

Reconstruction could be considered to ensure functionality for the future survival of the structure or to promote understanding of its heritage and function. This should only be undertaken if enough documentary or physical evidence exists to inform reconstruction. As for repairs, reconstruction should be undertaken with original materials wherever possible.

8.2.3 Strategy 3—Maintenance and monitoring

It is unrealistic to assume that a repair project can solve all the problems of a historic concrete structure. It is recommended that a maintenance plan be drawn up that includes a 5-yearly inspection. This should include site visits, inspections, analysis, recommendations and preparation of maintenance schedules. Funding allocation for this process is necessary.

8.2.4 Strategy 4—Documentation

It is good conservation practice to document all work and procedures undertaken. This ensures that there is a record and history of any changes to the structure, so that information is available should further work be required in the future. This will also be useful to inform maintenance and monitoring of the structure. This can be done by way of photographs, drawings and specifications.

8.3 IMPLEMENTATION OF CONSERVATION STRATEGIES

Once the conservation strategies have been determined, they can be implemented. This will require the production of drawings, specifications and contract documents for the proposed work, preferably undertaken by those involved in the analysis and with technical and conservation expertise.

Work of this nature is often extremely difficult to estimate and price. Although the nature of the work may be known, a large part of the extent of work required will often have to be determined as the work progresses. One way of dealing with this problem is to use an agreed schedule of rates for specified operations with a chosen specialist contractor.

9. Field guidelines

The investigation and evaluation of a historic concrete structure should preferably be undertaken by researchers, engineers or architects who are experienced in both concrete and in conservation, as explained previously. It is recognised, however, that expert or experienced advice will not always be available to field staff. Therefore, the purpose of this section is to provide a basis for informed judgements to be made at the site by field staff.

Effective fieldwork will depend on:

- Sound preparation
- Careful observation
- Thorough recording
- Accurate analysis

9.1 PREPARATION

Before visiting a site, it is important to ensure that adequate and appropriate equipment is available for the field. It will also always be helpful to have located as much documentary evidence as possible and, in particular, to have consulted the historical record, to find out as much as possible about the site and the historic artefact itself. This may include a search of local and national archives, including those within DOC. The objective will be to find anything that helps to understand the object as it was built, including:

- Its purpose
- How it functioned
- Its construction
- The history of its use
- Changes made over time

This will provide clues that will help understand its present appearance and condition.

9.2 SITE OBSERVATION

Examination of the object and its site is a critical activity. It will be important to be able to distinguish the historic artefact from its present surroundings, and to differentiate significant material or components from material that is not relevant—it is always possible that other objects that were not part of the original have been dumped at the site. This is where the preliminary research will prove valuable.

Changes to the site may have concealed parts of the object, and changes to the object itself, including collapse or being covered over by later material, may confuse the visual analysis. An important principle, however, is to suspend judgement and note everything as if it is relevant, then determine later by analysis whether this is in fact the case.

9.3 RECORDING

Recording is a logical extension of site analysis, and is intended to ensure that all information established at the site is noted and stored in a systematic manner. This is important for later analysis away from the site, particularly if another person needs access to the same information. It also forms a crucial part of the case history of the artefact, and may provide a basis for comparisons to be made at a later date. The level of detail that will be appropriate will depend, to some extent, on the scale of the site, its various components and the extent to which these are dispersed over the site.

As described in section 6.2, the site record should note:

- The site and its conditions
- A description of the structure and its materials and finishes
- The condition of the structure generally
- The type, extent and position of any visible deterioration

Useful records combine graphic and textual material, and may also include sampling of materials.

Graphic records combine photography, plans and detail drawings. Plans and detail drawings should be carefully and neatly annotated to show where photos have been taken, and to record factual detail such as dimensions, as well as impressions of condition, colour and anything else that may be a characteristic of change over time. In all recording, begin with the general and contextual, and then move on to the detailed and specific. Bear in mind that most recording is likely to be undertaken on paper no larger than A4 size, hopefully on a clipboard (anything larger can be too difficult in adverse weather conditions). On every drawing sheet, note the following:

- Site name
- Location
- Date
- Name of the investigator/recorder
- Title of the drawing
- Page number

When drawing, use constant line size for general drawing, with heavier lines to show outlines or edges. Where parts of an object are clearly missing, use broken lines to indicate the missing material. Where components are overhead, use dotted lines, or for beams, etc., use centre-line notation of dashed/dotted line. The drawings should be dimensioned (using running dimensions and a few overall dimensions) and should include:

- **Location plan** This could be a photocopied road map or ordinance survey plan with the site marked and annotated with a GPS reference. Note access points or tracks, and other property interests.

- **Site plan** This should cover the whole site (or if the site is very large, the immediate locality of the artefact) to provide reference points to key landmarks or other distinguishing features (e.g. Fig. 24). Some objects may be difficult to locate visually because of overgrowth or decay, in which case reference points with dimensions from the object will be useful for others looking to locate the site. Note these dimensions, using triangulation wherever possible to get the best possible fix. Show the extent of the artefact in its immediate landscape and identify main physical features.

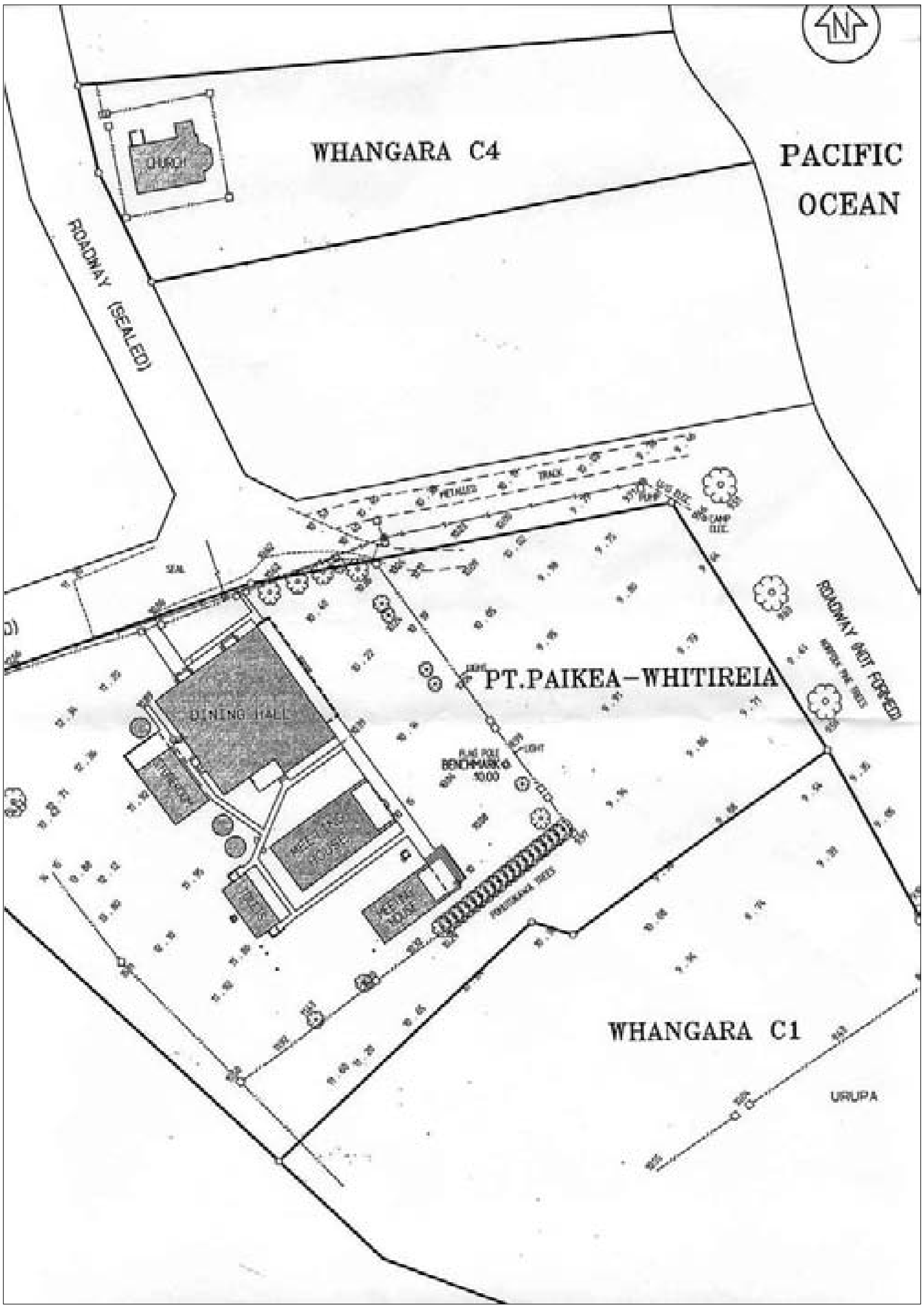

Figure 24. Surveyed site plan, showing key features, at Whangara Marae, near Gisborne (Grant & Cooke Ltd, Surveyors, Gisborne).

- **Detail plan** Draw the object again at a larger scale to provide plans at each level (including roof), showing key physical features in reasonable detail, with overall dimensions to show the relative position of the parts (e.g. Fig. 25). Use firm, clean lines to show main surface features, with thicker lines to show edges between main elements.
- **Elevations** Where possible, also sketch a view of the object from all sides, as close to the same scale as the plan. Similarly, note dimensions to show the relationship of the parts and heights above ground. It may be helpful to lightly shade some surfaces to show setback, or to use texture (such as dots) to indicate surface condition. Hatching (diagonal lines) is useful for indicating material covered over or missing.

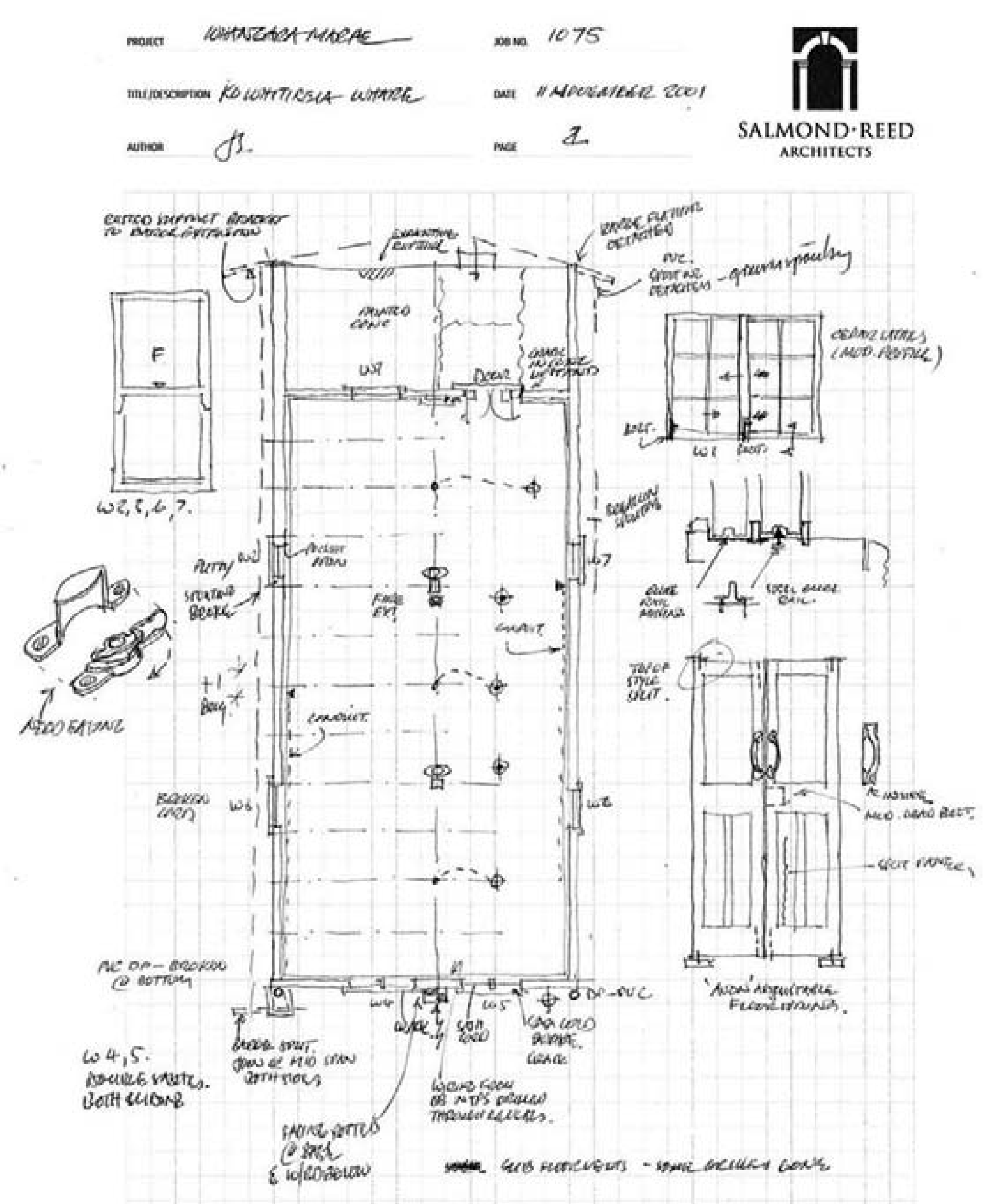

Figure 25. Site sketch plan for church at Whangara, near Gisborne, showing showing some construction details and recording the condition of various features.

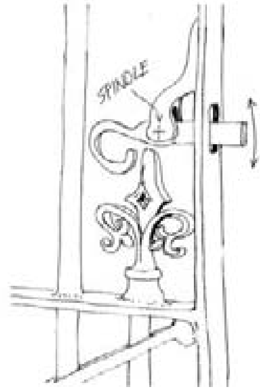

Figure 26. Sketch showing detail of door latch operation.

- **Details** It may be useful to make larger scale sketches of parts of the object to allow greater detail to be recorded, or to show how a particular component is made or may have functioned (e.g. Fig. 26).

Recording of the condition of the site and its artefacts may be adequately represented in notes on site drawings, together with photographs. However, it can be useful to also produce a table of items with observations noted, as ultimately the results of the inspection will need to be summarised in an accessible form for analysis, and tables provide a useful format for adding subsequent analysis and prescription for remedial works.

It may also be possible to take from the site samples of materials for analysis. This can be especially appropriate for materials such as concrete, since the precise nature of the concrete mix may require laboratory analysis to assist in determining a remedial process.

9.4 ANALYSIS

While some analysis will be possible at the site, a more considered conclusion may best be left until all evidence and information can be collated and compared. It is not always practicable to interpret archival material in the field, unless this has been thoroughly studied beforehand. On the other hand, copies of archival photographs may be enormously helpful for identifying otherwise formless items by their location on the site and relative to each other.

If possible, use the site drawings and measurements to produce accurate scale drawings of the site and the artefacts. These will be useful for analysis and will form a valuable record of the site at that point in time.

Post-site analysis allows considered examination of all the evidence from the site, from research, and also from analysis of samples that may have been taken at the site.

10. Acknowledgements

This document was circulated widely to professional and other interested commentators, and their responses have been incorporated into this version. Many other individuals have made valuable suggestions on matters of fact and format, and these have been incorporated wherever possible. We are particularly grateful for the detailed and pertinent suggestions made by Jim Dawson, Geoffrey Thornton, Owen Wilkes, Susan MacDonald, Trevor Butler, W.E. Hickman, Peter Lowe and Andrew Charleson. Some of the information contained in this report was compiled by How Sen Tan. Information on a range of historic structures, including the case-study water tower on Motuihe Island, was provided by DOC personnel, and early drafts of the initial report were reviewed by Dave Veart of the Auckland Conservancy. Derek Chisholm of BRANZ helped with technical enquiries.

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13. Glossary of technical terms

Active cracks Cracks that open and close, usually due to changing environmental conditions.

Bonding medium Material used to bond fresh concrete to existing concrete.

Carbonation A slow chemical reaction between atmospheric carbon dioxide and cement paste. It results in a lowering of the pH of the concrete. It also hardens the concrete and reduces its permeability progressively inward, creating layers in the concrete that undergo differential movement. Carbonation is accompanied by some shrinkage.

Cement An adhesive composed of a *dry hydrate* made into a paste with water. It is most often associated with Portland cement (artificially manufactured cement).

Cold joint The point at which two adjacent pours of concrete meet. Because the first pour has already set and partially cured, the bond between the two surfaces is weaker than the rest of the concrete and can open under stress.

Compatible materials Materials that have similar characteristics of expansion and contraction under changing environmental conditions.

Core drill A tool used to remove a core sample of concrete on site. The sample may then be tested in a laboratory for strength, unit weight, approximate mix proportions and cement content.

Crypto-florescence Similar to efflorescence, but occurs below the concrete surface, causing blistering and disintegration.

Curing The maintenance of optimum moisture and temperature conditions to promote to the best advantage the hydration of the cement during the setting and hardening process. This can be achieved by adding moisture by sprinkling with water or covering with wet sand or hessian, or by preventing moisture loss using plastic sheeting or liquid membrane curing compounds.

Dormant cracks Cracks that no longer open or close.

Dry hydrate Dry powder. Can refer to either non-hydraulic lime, hydraulic lime or hydraulic cement.

Drying shrinkage Reduction in volume of the concrete when some of the water in excess of that required for hydration evaporates from the mass, causing shrinkage.

Efflorescence Formed from soluble salts such as magnesium, sodium and, to a lesser extent, calcium, potassium and lime compounds, which crystallise on the surface of the concrete in the form of a white powder.

Elastomeric sealant A sealing material that returns to its original shape when not under stress.

Feathered edge An edge to a cavity or crack that attains depth gradually and unevenly, as opposed to a steep, clean edge.

Free water All water contained by concrete, mortar or plaster in excess of that chemically held as water of crystallisation.

Grading The grading of aggregate refers to the quantities of particles of various sizes. Well graded aggregate has a continuous range of aggregate particle sizes.

Hardening The friable mass becomes progressively more tightly bonded together and less friable until it is firmly set.

Honeycombing Where a large part of the cement paste and fine aggregate was removed from the concrete during pouring, leaving voids of cement-coated large aggregate. It is usually caused by poor compaction or leaking formwork.

Hydrated lime Dry powdered lime, sometimes known as 'hydrate', 'dry hydrate' or 'bag lime'. Hydrated lime can be either hydraulic or non-hydraulic lime and is usually sold in paper sacks through builders' merchants.

Hydration A complex process that involves several simultaneous series of chemical reactions during which the main constituents of cement (the calcium silicates and aluminates) react with water to produce hydrates and numerous other compounds. The fact that the reaction products are insoluble gives concrete its characteristic durability in the presence of water.

Hydraulic cement See 'cement'.

Hydraulic lime Lime that sets and hardens under water because of the aluminium silicate or burnt clay content. Hydraulic limes can be separated into three loose categories: eminently hydraulic, moderately hydraulic and feebly hydraulic. (Cf. 'natural cement'.)

In situ When used in the context of concrete structures, this means that the concrete was cast on site. Originally, this meant that the components of cement, fine aggregate, coarse aggregate and water were mixed on site as well. In recent times, however, concrete is often brought to the site pre-mixed and then cast on site.

Lime putty Putty-like substance that is created when an excess of water is used during the *slaking* process. Can be kept for long periods in an air-tight container.

Mortar A mix of fine sands, either *lime putty*, hydrated lime or Portland cement, and water. Used in the fabrication of brick or masonry work.

Natural cement The product of burning limestone, which, in its natural state, contains sufficient siliceous impurities (15%) to produce a lime with hydraulic properties. Natural cements set rapidly, even under water, but cannot be slaked in lump form. (Cf. 'hydraulic lime'.)

Non-hydraulic lime Slaked lime without any hydraulic properties. Can be known as pure lime. Non-hydraulic limes will not set under water. They take an initial weak set just by drying out and they only develop strength by the slow process of induration (the process of hardening) at the exposed surface.

Portland cement (Ordinary Portland cement—OPC.) The product of burning an artificially prepared and precisely controlled mixture of limestone and clay (silicates and aluminates) at approximately 1300°C. The resulting clinker is then finely ground to produce cement. Portland cement is now more usually known as 'general purpose' cement.

Poultice A mix of an inert fine powder with a solvent or solution for removing stains from concrete. These are blended into a smooth paste, which is then applied over the stain using a trowel or spatula. The solvent or solution permeates the concrete and dissolves the stain. It then gradually moves back into the poultice and evaporates, leaving some of the staining material in the poultice.

Pozzolans Materials containing silica, alumina and sometimes iron oxide. When combined with slaked hydrated lime, pozzolans add hydraulic properties to the lime. Natural pozzolans were found by the Romans near Mt Vesuvius in volcanic ashes from Pozzuoli, hence the name. Other natural pozzolans used in the past were terras or trass found in Germany on the banks of the upper Rhine, and volcanic ash (santourin) from Greece. Artificial pozzolans can be produced from crushed or burnt clay bricks and tiles, and (in more recent times) granulated blast furnace slag and pulverised fly ash.

Quicklime Calcium oxide—also known as 'lump lime' and 'unslaked lime'. Formed by heating raw limestone and other lime-rich materials in a kiln. This removes carbon dioxide from the stone leaving calcium oxide. Quicklime reacts with moisture to form calcium hydroxide; therefore, it must be handled with great care.

Ramming A historic method of consolidating concrete in the form, by pounding with a heavy wooden rammer until water began to appear at the surface.

Reaction product The compound resulting from a chemical reaction.

Sand A form of silica. May be classified according to its origin, e.g. pit sand, river sand and sea sand. Washed pit sand is preferred, as river sand has round, smooth grains that reduce adhesive value, and sea sand will be contaminated by salt, which will attract dampness and cause efflorescence in cured concrete.

Segregation Separation of the course aggregate from the cement, water and fine aggregate as a result of gravity or lateral movement of a wet mix or excess vibration.

Setting When a mixture of cement, aggregate and water loses its plasticity and becomes friable. It will not become plastic again upon mixing with water.

Slaked lime Quicklime that has been mixed with water to form calcium hydroxide. The reaction generates considerable heat and the product is highly corrosive.

Slaking The reaction that occurs when quicklime is mixed with water.

Spalling The loosening and subsequent loss of concrete from a structure due to expansive forces in the concrete. This usually occurs as a result of the expansive force of steel rusting: the rust from corrosion of steel has three or more times the volume of the original steel. A more serious form of spalling is delamination,which is when a whole layer of concrete comes loose from the structure.

Vibrating The current method of consolidating freshly poured concrete in the forms by immersing a vibrating head into the concrete.

Water:cement ratio The chief factor that controls strength for a given cement content. Water is needed to wet the surface of the aggregate and to hydrate the cement. All water additional to this is ‘free water’, which increases plasticity and workability, but reduces strength and durability.

Workability The ease with which good hydration of the cement takes place, and ease of placement in the forms and compaction of the concrete so that there are no voids.

Appendix 1

WATER TOWER, MOTUIHE ISLAND—CASE STUDY

Introduction

The water tower on Motuihe Island, Hauraki Gulf, Auckland, was erected by the Navy in 1941 (Fig. A1.1). It was one of many structures built as part of rapid infrastructure development during WWII, and was erected to store sea water to be used for fire-fighting purposes. It comprised a round reinforced concrete tank supported on reinforced concrete posts with brick masonry infill panels. HMNZS Tamaki was a naval training base on the island and part of Auckland's WWII coastal defence complex.

Naval records from 1947 noted that the low-pressure water tower and the reticulation system for fire protection were built during the rush period of Tamaki's early development when it was considered to be a training establishment for the War period only, and that at this time it was already inadequate, as the site had now become a permanent training centre. Additional reservoirs were subsequently built to supplement the water supply for fire-fighting.

The first part of the process of investigation and conservation of the tower is outlined below. This serves to show a method for evaluating structures in the field. As outlined in section 6, investigation and evaluation cover:

- Research and document review
- Field survey, including site record, on-site testing, photographs and freehand drawings
- Measured drawings
- An analysis and report based on the above

In this instance, no testing was undertaken.

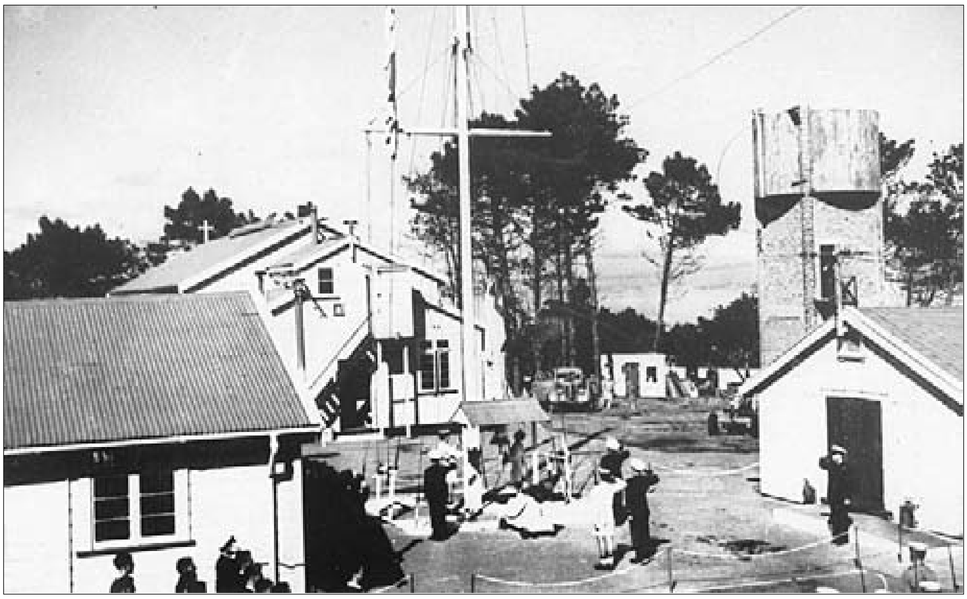


Figure A1.1. Water tower, Motuihe Island, near Auckland, c. 1950, showing structure with original doors, windows, and brickwork intact (held on file at Auckland Conservancy, DOC).

Research and document review

Research at the National Archives into Public Works Department, Defence and Naval files indicated that the water tower was one of a number of structures built in 1941 for HMNZS Tamaki Naval Training Base. No original drawings or specifications were found for the structure.

There are extensive specifications for later concrete reservoirs built in the 1950s, which give details of not only materials and quantities, but also workmanship and curing of the concrete. It is not certain, however, that these specifications matched those for the water tower. As with many other defensive constructions of the time, the structure was built in a great hurry together with numerous other buildings on the site, and very little documentation survives.

Local history and background

Records of the Tamaki site from 1948 noted that all construction materials had to be transported to the island. The concrete would have been based on ordinary Portland cement and well-graded, clean aggregate. It is possible that water for both the concrete mix and curing was contaminated with chloride. It is not known whether the construction was carried out by contractors or by defence force staff, and this may have affected the quality of workmanship—particularly the amount of concrete cover over reinforcing steel.

A number of old photographs and drawings have been located in National Archives, and copies of these are held by the Department of Conservation.

Survey

Site conditions

The water tank is situated on Motuihe Island in the Hauraki Gulf. The site is flat, in a high-wind area, and exposed to sea air and thus airborne chlorides. The site is remote and does not have general services such as an electricity supply. The water tank is the most prominent of the few surviving structures on the site. It is no longer used for water storage.

Structure

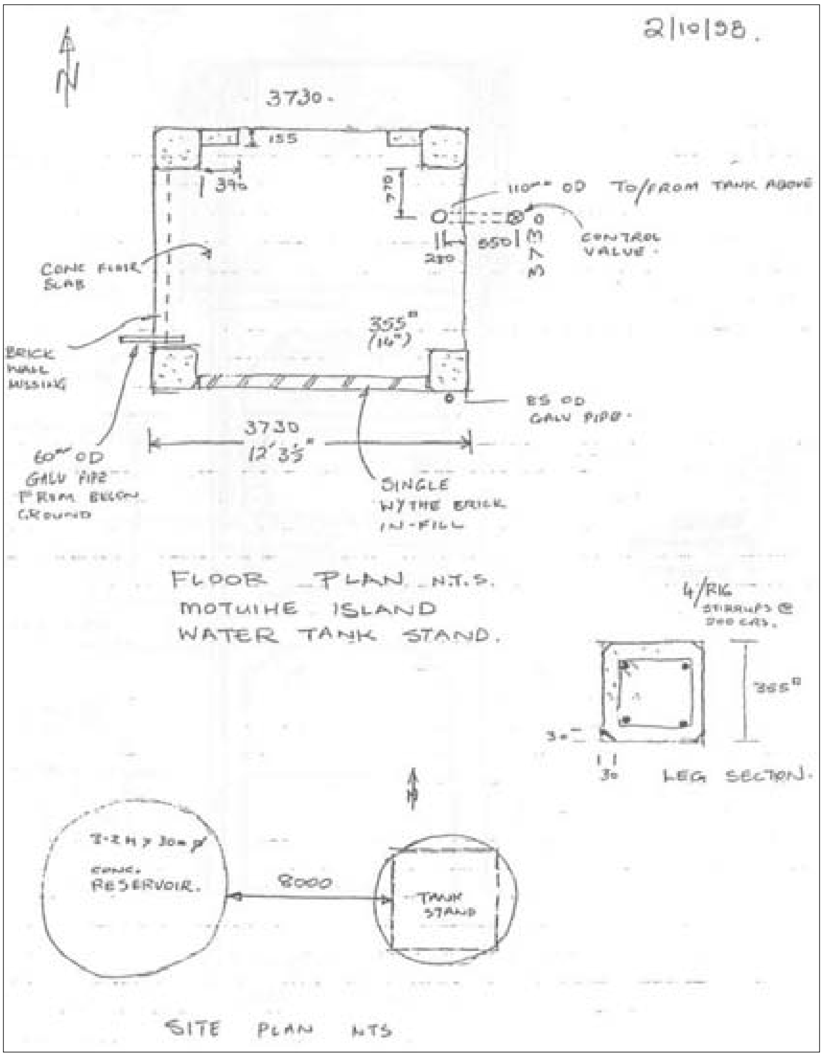
The structure has a reinforced concrete frame with brick infill panels (Fig. A1.2) supporting a circular, reinforced concrete water tank. Its overall height is 12.5 m and the tank is 5.2 m in diameter (Figs A1.3 & A1.4).

The structure is currently in poor condition, with deteriorating brick and concrete. The bricks of two of the brick infill panels have collapsed or have been removed, leaving some remaining brickwork unsupported. The site is generally untidy, with loose building rubble lying in and around the structure.

Visible defects and deterioration

A range of distinct defects have been identified in both the concrete and the brick masonry. These are summarised below. A selection of photographs is included to explain the site context and to illustrate specific or characteristic defects.

Figure A1.2. Site plan and floor plan sketch of water tower, Motuihe Island, and surrounding buildings, late 1940s (held on file at Auckland Conservancy, DOC)..



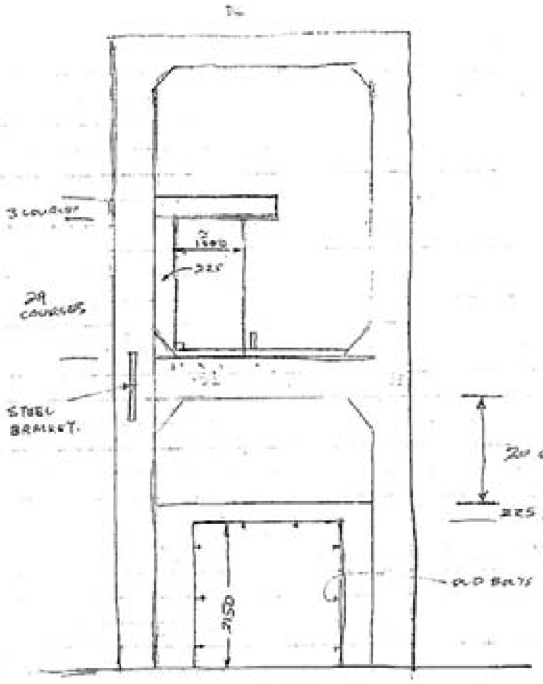


Figure A1.3. North elevation of water tank, Motuihe Island.

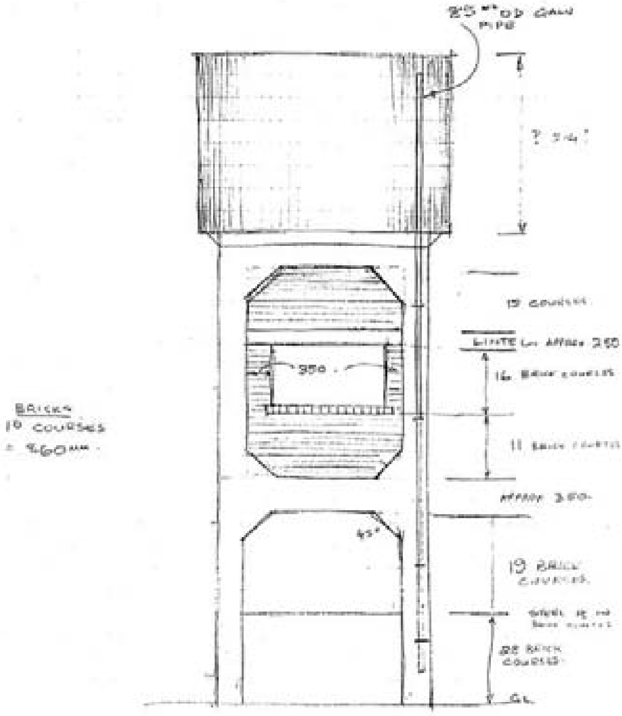


Figure A1.4. South elevation of water tank, Motuihe Island.

Analysis and report

TABLE A1.1. TABLE OF DEFECTS IDENTIFIED.

TYPE OF DEFECT		CAUSE	SEVERITY	RATE	POSSIBLE CONSEQUENCES
Reinforced concrete					
D1	Crazing	Differential thermal and moisture movement	Mild	Medium	Vulnerable to further corrosion
D2	Pre-spalling cracking	Corroding steel with insufficient concrete cover	Moderate	Medium	Vulnerable to further corrosion
D3	Long edge cracks	Exposure and wetting of corners, subsequent corrosion of steel	Moderate	Medium	Vulnerable to further corrosion
D4	Short edge cracks	Exposure and wetting of corners, subsequent corrosion of steel	Moderate	Medium	Vulnerable to further corrosion
D5	Structural crack	Shearing stress in concrete due to weakening of the structure	Moderate	Slow	Loss of strength
D6	Spalling concrete	Corrosion of steel and resulting expansive forces	Severe	Rapid	Loss of strength, safety hazard, vulnerable to further corrosion
D7	Delamination	Corrosion of steel and resulting expansive forces	Severe	Rapid	Loss of strength, vulnerable to further corrosion, safety hazard
D8	Efflorescence	Sulphates leaching out	Mild	Medium	Unsightly
Brickwork					
D9	Weathering	Variable quality of bricks; some poor quality soft bricks	Moderate	Medium	Vulnerable to further corrosion
D10	Mortar joints weathered and disintegrating	Weathering and exposure due to loss of other brickwork and joinery	Moderate	Medium	Vulnerable to further corrosion
D11	Unsupported brickwork	Removal of adjacent brickwork	Severe	Rapid	Loss of strength, safety hazard
Other fabric					
D12	Rusting steel bolts	Chloride attack and moisture exposure	Severe	Rapid	Loss of the material and damage to surrounding material
D13	Rusting galvanised steel pipe	Chloride attack and moisture exposure	Severe	Moderate	Deterioration of the material & damage to surrounding material
D14	Delaminating plaster	Differential thermal and moisture movement	Severe	Rapid	Safety hazard

Summary of defects and deterioration

The principle cause of damage and deterioration in the structure is corrosion of the reinforcing steel, resulting in spalling of the concrete. Brick masonry panels have been removed from the base and original joinery has been removed from external openings. Repairs are required to stabilise the structure, which is now in poor condition.

The deterioration is due to chloride attack and weathering by the aggressive sea environment. There is generally insufficient concrete cover of the steel reinforcing to provide it with adequate protection. The use of the tower to store salt water means that it would have been continuously exposed to chlorides during its working life. Although no measurement has been taken, the structure is more than likely to have a very high chloride content. The loss of the brickwork from the base and removal of the external joinery has exacerbated the problems by exposing the structure to weathering.

In its current state (July 1999), the condition of the structure can be expected to deteriorate rapidly in the absence of any intervention. The process of corrosion is well advanced and is accompanied by loss of strength as well as loss of concrete surface, i.e. loss of both tensile and compressive strength.

This will ultimately result in the deterioration of the structure to a point where it has to be either completely reconstructed or demolished.

Identified defects and deterioration are analysed in Table A1.1 according to type, cause, degree, rate of activity, and possible consequences.

Recommended strategies

The following repair strategies are recommended for the repair of the water tower. These are intended to ensure the continued survival of the structure and to make it safe for public access. The recommended measures should arrest its present decline but are not intended to restore its original function of water storage.

1. Spalling and loose concrete should be removed back to sound concrete.
2. Loose bricks should be removed for reuse (unless severely weathered).
3. A protected outlet should be designed and made to ensure that the water tank is always drained and does not accidentally store water.
4. The corroded steel should be cleaned back to clean metal and sealed with a suitable epoxy coating.
5. Chloride extraction should be undertaken to remove the chloride ions from the structure.
6. The structure should be checked by a structural engineer during this process to ensure that the steel and concrete and the structure as a whole are still sufficiently strong to be safe and carry their own weight (but not that of a water load).
7. Previously removed and damaged brickwork should be replaced to match the existing brickwork as closely as possible.
8. Damaged and weathered mortar joints should be repaired with material to match the original.
9. The spalled concrete should be replaced with Portland cement concrete that matches the original as closely as possible in strength, permeability and appearance. Use of a low water to cement ratio and thorough curing will ensure minimum shrinkage and thus greater adherence and less cracking. Consideration should be given to careful use of admixtures and a bonding agent to aid in this process of repair.
10. Efflorescence should be scrubbed off with water.
11. Consideration should be given to replacing the lost joinery, as this will considerably lessen the exposure of the structure.
12. Once the concrete has been repaired, a surface treatment can be applied that will provide chloride protection. This must be breathable, i.e. be water vapour permeable not water permeable, to ensure that moisture is not trapped inside, but should ensure that water runs off the surface of the structure rather than soaking in.
13. Following on from this, there should be interpretation of the structure and the site and its historical context.
14. A system of maintenance and monitoring should take place on a 5-year basis, as no process of repair can expect to solve all future problems, especially for reinforced concrete in an aggressive environment. As part of this process, the condition of the structure should be reviewed and minor maintenance and repairs should be undertaken.

New Zealand Government