DURABILITY OF CONCRETE ROAD BRIDGES IN NEW ZEALAND

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AN IMPORTANT NOTE FOR THE READER

The research detailed in this report was commissioned by Transfund New Zealand.

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CONTENTS

APPENDICES

FIGURES

TABLES

EXECUTIVE SUMMARY

An estimate is that over 10,500 bridges with concrete superstructures on New Zealand roads are maintained by Transit New Zealand and local authorities together. The project detailed in this report sought to identify means by which these bridges could be more effectively managed and their durability improved.

Transit New Zealand and selected local authorities provided information from their records to identify the age distribution and proximity to the coast of their bridges. Then Transit New Zealand regional offices and the local authorities completed a questionnaire on common durability problems, the use of computerised bridge management systems, and the treatment of reinforcement corrosion. The information does not necessarily apply to the entire bridge stock.

Principal findings were as follows:

- Transit New Zealand's Bridge Descriptive Inventory contains detailed descriptions of most of New Zealand's state highway bridges. Local authority records are generally less complete. Bridges of unknown age comprise 4% of the state highway stock and 17% of those administered by the 15 local authorities who could provide information on age distribution.

- Concrete state highway bridges that are more than 50 years old comprise 32%, compared to the 14% of bridges administered by the 15 local authorities. Bridges built since 1970 make up 21% of state highway bridges and 30% of the local authority bridges.

- All the bridge controlling authorities who were surveyed had formal inspection programmes which should help early identification of problems.

- A well maintained, user-friendly, universal management system would improve consistency of data recorded by the different bridge controlling authorities, and could therefore help to establish appropriate maintenance funding levels.

- Personnel responsible for bridge management have a reasonable understanding of durability issues, but need more current information on treatments for reinforcement corrosion.

- Maintenance and durability problems affect up to 40% of bridges, and are more common on older bridges.

- Deck joint deterioration is the most common maintenance problem on concrete bridges. Bridges of all ages are affected.

- Surface scaling, indicative of frost or chemical attack, was not well recognised or recorded in some regions/districts where it might be expected, so no comment can be made on the incidence of these types of deterioration.

- Linear cracking, usually caused by shrinkage, is more common in the North Island. This might be related to the types of aggregate used.

- Reinforcement corrosion is potentially the most threatening concrete durability problem although routine maintenance and inspection of bridges currently accounts for the bulk of the bridging repair and maintenance bill.

- Reinforcement corrosion is more common in older bridges and is usually related to design or construction defects. Improvements in design and construction in the last 50 years, particularly with the introduction of modern precast practice, mean that the risk will not necessarily increase as the bridge stock ages.

  Current New Zealand standard specifications for concrete construction, if adhered to, ensure a maintenance-free life of at least 50 years. Thus construction industry training programmes are important to ensure the durability of bridges to be built in the future.

- Reinforcement corrosion is more common in bridges exposed to salt contamination from seawater.

- Epoxy repair materials are widely used to repair spalled concrete although the repairs often disbond. Repair materials are often selected on the basis of familiarity and convenience.

  Cost is also important and has been a prohibiting factor in the introduction of electrochemical treatments. Although initially more expensive, the long-term durability offered by electrochemical repair techniques should be considered when repair materials are selected.

As a result of the project, the following recommendations are made:

- Design and Construction Issues
  - Ensure that current specifications for concrete construction are adhered to in bridge design and construction.

- General Management of Bridge Stock
  - The improvement recommendations, which are anticipated to arise from the National Bridge Contract, should be promptly implemented to maximise potential benefits for all bridge controlling authorities.
  - The National Bridge Consultant's advice should be disseminated to local authorities to assist the development of bridge management plans.

- Long-Term Durability Issues
  - Long-term durability should be considered when selecting repair systems for concrete damaged by reinforcement corrosion.
  - An independent evaluation of the effectiveness of electrochemical repair systems installed overseas should be carried out.
  - The performance of methods currently used to accommodate bridge superstructure movements (e.g. deck joints) should be investigated so that shortcomings in their effectiveness and durability can be overcome in future bridge construction.
  - The incidence of scaling damage on bridges that are likely to be affected by freeze-thaw effects should be further investigated.

- Reference Documentation
  - Transit New Zealand's *Bridge Inspection and Maintenance Manual* should be revised to include information on desalination and realkalisation and on proprietary cementitious repair materials.
- Future Directions
  - Methods of predicting future deterioration in concrete bridges should be investigated so that cost-effective preventive action can be taken before significant damage develops.
  - A proactive approach to bridge maintenance issues, whereby remedial work can be carried out on bridges more than 50 years old, should be developed to reduce future maintenance costs and add to the life expectancy of the structure.

ABSTRACT

Transit New Zealand regional offices and selected local authorities were asked for information from their records on age and proximity to the coast of their bridges. Together they maintain more than 10,500 bridges with concrete superstructures on New Zealand roads. They also completed a questionnaire to identify common durability problems on concrete bridges, and to identify ways that would enable the bridge asset to be more effectively managed.

Responses showed that most concrete bridges are in acceptable condition. Deck joint deterioration is the most common maintenance problem, and affects bridges of all ages. Reinforcement corrosion is more common on older bridges and on those near the coast. Current standard concrete construction specifications ensure at least a 50-year service life if they are followed during design and construction. A national bridge management system would provide a cost-effective means of managing information on bridge condition, location and construction details.

1. INTRODUCTION

Concrete bridges form a major part of the bridge assets on the New Zealand road network of state highways and local authority roads.

The state highway network includes 2,411 bridges and 1,223 culverts, and more than 90% of the superstructure elements (beams and/or decks) on the bridges are constructed of reinforced concrete. The local authority road network includes approximately 13,000 bridges and culverts, of which it is estimated 80% are bridges and more than 80% of these include concrete superstructure elements. Thus there are more than 10,500 concrete bridges on the New Zealand road network.

Concrete durability is becoming an increasingly important issue because of the large population of aging bridges. On the state highway network, for example, more than 75% of reinforced concrete bridges were constructed before 1970. Apart from age, durability may also be affected by location, design, detailing, quality of concrete, and quality of construction. The concrete deterioration mechanisms which may affect the durability of the bridges are:

- reinforcement corrosion caused by chloride contamination, or
- carbonation of the concrete and
- disintegration of the concrete matrix caused by factors such as alkali aggregate reaction (AAR), freeze-thaw attack, and sulphate attack.

Reinforcement corrosion as a result of chloride contamination is the most significant problem affecting New Zealand's concrete bridges. As chlorides are usually an external contaminant from the sea, bridges within the coastal margin have a higher risk of being affected by reinforcement corrosion.

This risk is further increased when poor detailing and inferior quality construction practices reduce the natural protection provided by the concrete to the reinforcing steel. In many cases the construction practices may simply reflect the materials, methods and knowledge available at the time of construction. The importance of design and detailing is recognised in NZS 3101: Part 1: 1995, and durability exposure classifications are defined depending on the proximity of the coastline and the strength and direction of the prevailing wind.

The condition of New Zealand road bridges is monitored by road controlling authorities who determine repair and maintenance requirements by physical inspection. These regular inspections provide the means to maintain the serviceability of the bridges, and thereby monitor any deterioration in the fabric of the concrete bridges indicating a reduction in durability.

Additional information on concrete bridge durability has been collected in the past from research projects funded by the Structures Committee of the Road Research Unit, National Roads Board in the 1980s.

An overview of the durability of concrete bridges was obtained by special inspection of some 300 bridges in the lower North Island between 1982 and 1984 (Rowe & Freitag 1984). Nicholas (1987) carried out a survey of road controlling authorities to determine the extent of maintenance problems in bridge structures.

Recent interest in concrete bridge durability has been heightened by the participation of Transit New Zealand in AUSTROADS Project T&E.B.41, 3B.4.1 Concrete Structures - Durability, Inspection and Maintenance Procedures (AUSTROADS 1997). A brief position paper was prepared as a contribution to this project (Bruce & McGuire 1996, Appendix 1 to this report), summarising concrete durability problems in New Zealand bridges.

This report presents the findings of a research project carried out to expand on that summary paper by obtaining an overview of the durability problems encountered in New Zealand concrete road bridges. The specific aims of the research are to identify the durability problems encountered, how the problems are detected and further investigated, the measures taken to remedy these problems, and how well the remedial treatments have performed. The ultimate outcomes of this research are the recommendations to enhance bridge durability and to provide road controlling authorities with the information required to manage their bridge assets more effectively.

The methodology of this research is based on:

- Collection of data on concrete bridges administered by both Transit New Zealand and selected local authorities. Information has been collected on bridge numbers, type, age, and proximity to the coast to identify the exposure environment, on a regional basis. The data were then compared to the durability exposure classifications adopted by NZS 3101: Part 1: 1995 to establish the durability problems that are likely to affect the bridges in each region.
- A postal survey (by questionnaire) of Transit New Zealand regions and selected local authorities to identify common durability problems, how they are detected and further investigated, the repair methods used, and how effective they are.

2. METHODS

2.1 State Highway Bridge Data Collection

Transit New Zealand maintains a database system known as the *Bridge Descriptive Inventory,* which records up-to-date descriptive information about highway structures. In the inventory, each structure is uniquely identified by the highway number on which it is situated and the route position on that highway. Other information recorded includes:

- structure type (i.e. bridge, culvert, bailey bridge),
- age of structure,
- total bridge length and span lengths,
- maximum clearance above ground,
- construction materials,
- deck wearing surface,
- foundation type,
- type of expansion joints.

This project considered only those structures designated as bridges in the inventory, and not culverts or bailey bridges.

Information on bridge age was sorted for each of the seven roading districts, then manipulated for presentation by decade of construction.

Structural elements in a bridge which may be concrete are the abutments, piers, beams and decks. For durability purposes the critical elements are in the superstructure (i.e. beams and deck), and so any bridges in the inventory which included concrete in either of these elements were designated as a concrete bridge. The inventory "fields" searched were:

Deck Material

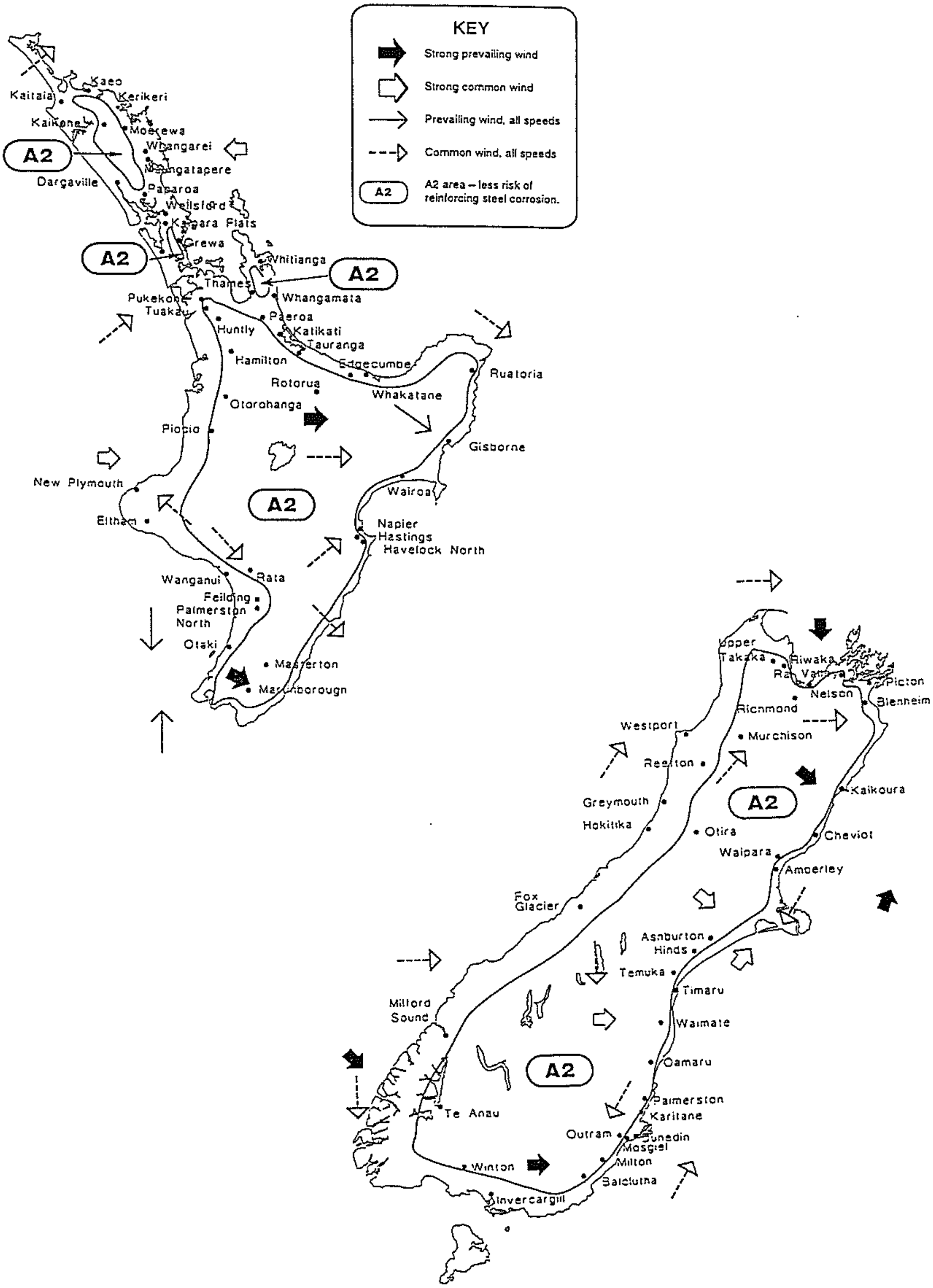
Code	2	reinforced concrete
	3	prestressed concrete

Superstructure Material (assume beams)

Code	2	concrete cast-in situ reinforced
	3	concrete cast-in situ prestressed
	4	concrete precast reinforced
	5	concrete precast pretensioned
	6	concrete precast pre/post-tensioned

The location of each bridge on the state highway network was determined in relation to the durability exposure classifications in NZS 3101: Part 1: 1995 (Figure 2.1). The boundary between the coastal perimeter (exposure classifications B1, B2 and C) and inland (exposure classification A2) was plotted on the regional state highway network maps, and the number of bridges in the coastal perimeter was determined from the route position of each bridge.

Figure 2.1 Exposure classification map for New Zealand
(taken from NZS 3101: Part 1: 1995).



2.2 Local Authority Bridge Data Collection

There are 75 local authorities in New Zealand, all of which administer some concrete road bridges. No central database is maintained to record descriptive information on these bridges, so relevant data were requested from selected local authorities. Of these authorities 20 were selected using the following criteria:

- Each local authority must administer more than 100 bridges, apart from two city councils selected to represent bridges in a municipal locality.
- The sample represents a range of durability environments, as defined by the exposure classification maps in NZS 3101: Part 1: 1995.
- The sample represents climatic variations.

The 20 authorities selected (locations shown in Figure 2.2) were:

Ashburton District Council
Auckland City Council
Banks Peninsula District Council
Central Otago District Council
Christchurch City Council
Far North District Council
Gisborne District Council
Hastings District Council
Hurunui District Council
Rangitikei District Council
Rodney District Council
Ruapehu District Council
Southland District Council
South Taranaki District Council
South Wairarapa District Council
Tararua District Council
Tasman District Council
Thames-Coromandel District Council
Waikato District Council
Westland District Council

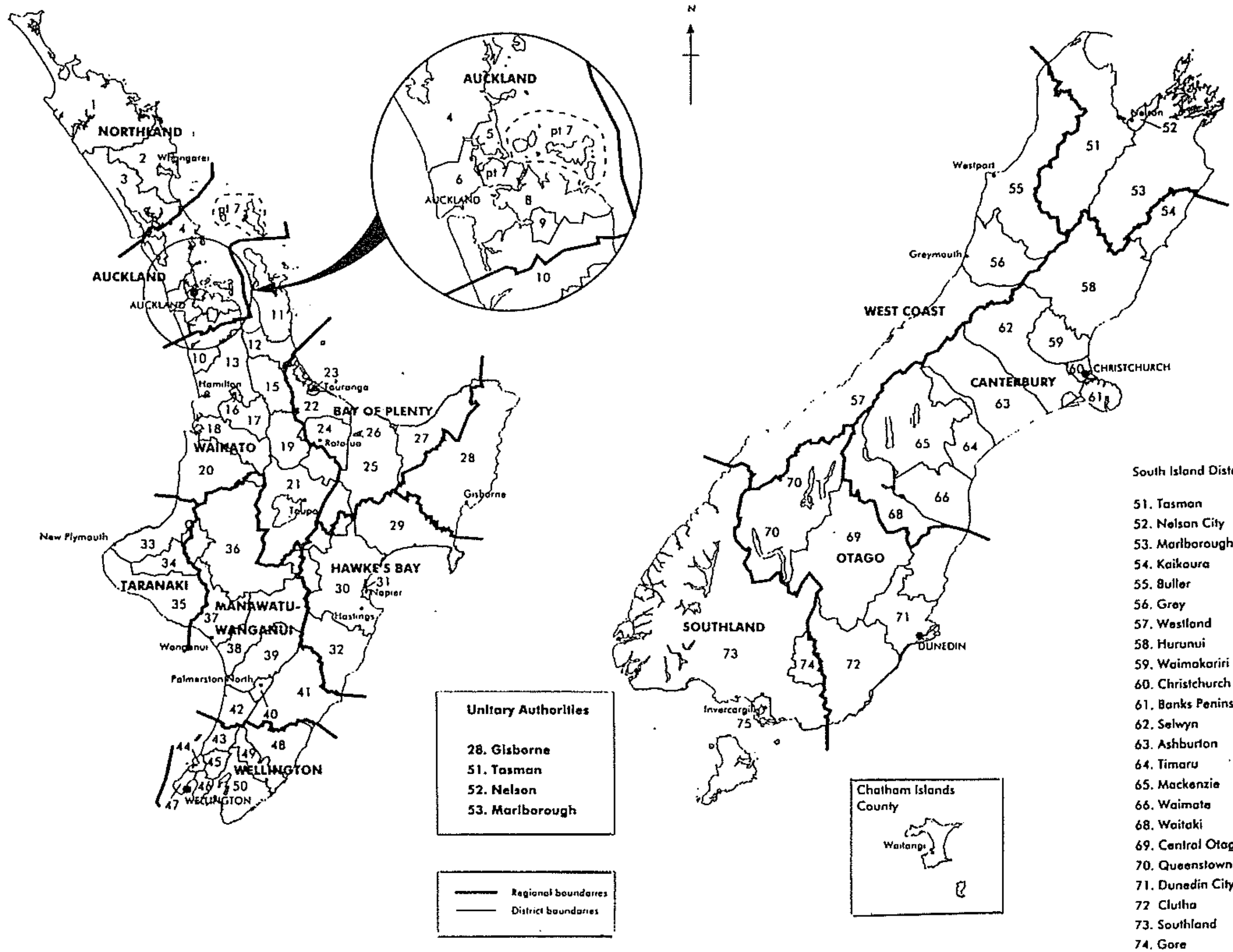
Of the 20 local authorities, 19 responded to the request for information, but not all the data requested were available from every local authority. Useful data on bridge ages were maintained by 15 of the 19, and sufficient data were available from most authorities to allow the number of bridges with a concrete superstructure to be identified. It was difficult to distinguish between bridges and culverts because of the nature of some databases.

Local authorities record the location of bridges in several different ways, ranging from a numbering system to identify each bridge on a district map, by road or street name, through to no formal record of bridge location. Nevertheless it was possible to either estimate or accurately determine the percentage of bridges in each local authority that are located in the NZS 3101: Part 1: 1995 coastal perimeter exposure classification.

Figure 2.2 Boundaries of territorial local authorities, New Zealand.

North Island Districts

1. Far North
2. Whangarei
3. Kaipara
4. Rodney
5. North Shore City
6. Waitakere City
7. Auckland City
8. Manukau City
9. Papakura
10. Franklin
11. Thames - Coromandel
12. Hauraki
13. Waikato
15. Matamata - Piako
16. Hamilton City
17. Waipa
18. Otorohanga
19. South Waikato
20. Waitomo
21. Taupo
22. Western Bay of Plenty
23. Tauranga
24. Rotorua
25. Whakatane
26. Kawerau
27. Opotiki
28. Gisborne
29. Wairoa
30. Hastings
31. Napier City
32. Central Hawke's Bay
33. New Plymouth
34. Stratford
35. South Taranaki
36. Ruapehu
37. Wanganui
38. Rangitikei
39. Manawatu
40. Palmerston North City
41. Tararua
42. Horowhenua
43. Kapiti Coast
44. Porirua City
45. Upper Hutt City
46. Hutt City
47. Wellington City
48. Masterton
49. Carterton
50. South Wairarapa



South Island Districts

51. Tasman
52. Nelson City
53. Marlborough
54. Kaikoura
55. Buller
56. Grey
57. Westland
58. Hurunui
59. Waimakariri
60. Christchurch City
61. Banks Peninsula
62. Selwyn
63. Ashburton
64. Timaru
65. Mackenzie
66. Waimate
68. Waitaki
69. Central Otago
70. Queenstown - Lakes
71. Dunedin City
72 Clutha
73. Southland
74. Gore
75 Invercargill City

2.3 Postal Survey

The postal survey was designed to obtain information on the bridge durability problems encountered by road controlling authorities. A copy of the survey is included in Appendix 2 to this report. Respondents were asked questions on the type and frequency of design- and construction-related defects, the frequency and distribution of durability defects, the frequency of certain maintenance activities, their inspection programmes and data management systems, their maintenance costs, and the treatment of damage due to reinforcement corrosion. The survey was prepared with the assistance of an environmental planner skilled in the preparation of postal surveys.

Initial responses from road controlling authorities (Section 2.2 of this report) took longer than expected. It was therefore decided not to pre-test the survey in case this delayed the distribution and gave the respondents insufficient time to respond.

The survey was sent to the Regional State Highway Managers of all seven Transit New Zealand regions, and to the local authorities who had provided descriptive information on their bridge stock by the time the survey was sent (Section 2.2).

Where the question required the respondent to "tick the boxes which apply", data were analysed by tallying the number of responses for each condition. Where respondents were asked for a description, common responses were identified. Comments of general interest have been reproduced in Section 4.10 of this report.

3. SURVEY OF AGE & LOCATION OF BRIDGES

3.1 State Highway Bridges

3.1.1 Number of Bridges

The New Zealand state highway bridge stock consists of 2,411 bridges, of which 94% include cast-in situ or precast concrete in the superstructure (deck and/or beams). There are also 1,223 culverts on the state highway road network. Of the total of 3,634 bridges and culverts, less than 6% are single lane structures (Transit New Zealand 1996). The bridges are included in 14 road districts which are administered by the seven Transit New Zealand regional offices. A breakdown of the number of bridges and culverts managed in each road district is included in Table 3.1.

Table 3.1 Stock of state highway bridges and culverts.

Road District	Region	No. of bridges and culverts	No. of bridges	No. of bridges with concrete superstructure*	No. of culverts
1	Northland	260	164	159	96
2	Auckland	228	192	189	36
3	Waikato	417	237	214	180
4	Bay of Plenty	202	139	134	63
5	Gisborne	118	75	74	43
6	Hawke's Bay	120	72	67	48
7	Taranaki	146	100	95	46
8	Manawatu/Wanganui	342	196	185	146
9	Wellington	131	87	77	44
10	Marlborough/Nelson/Tasman	248	163	155	85
11	Canterbury	402	255	235	147
12	West Coast	467	291	263	176
13	Otago	292	208	198	84
14	Southland	261	232	232	29

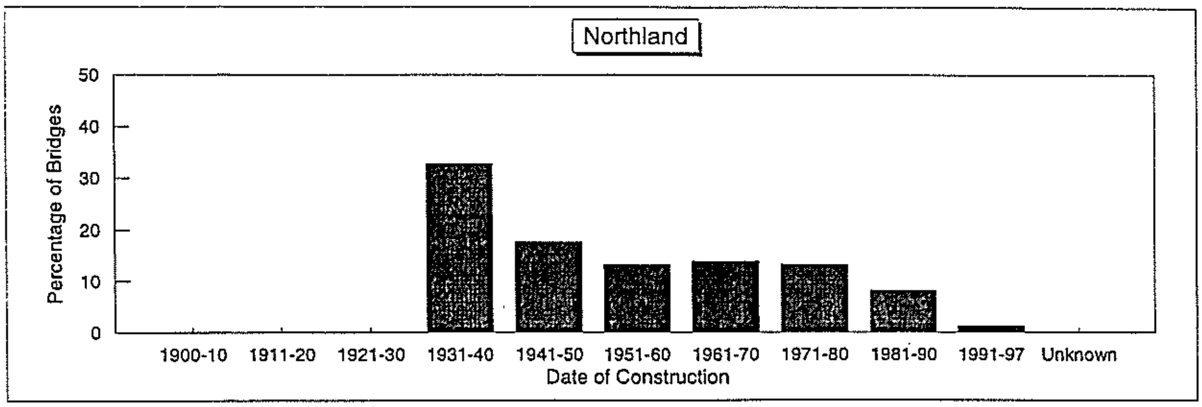
* Concrete superstructure - beams and/or deck constructed of cast-in situ or precast concrete.

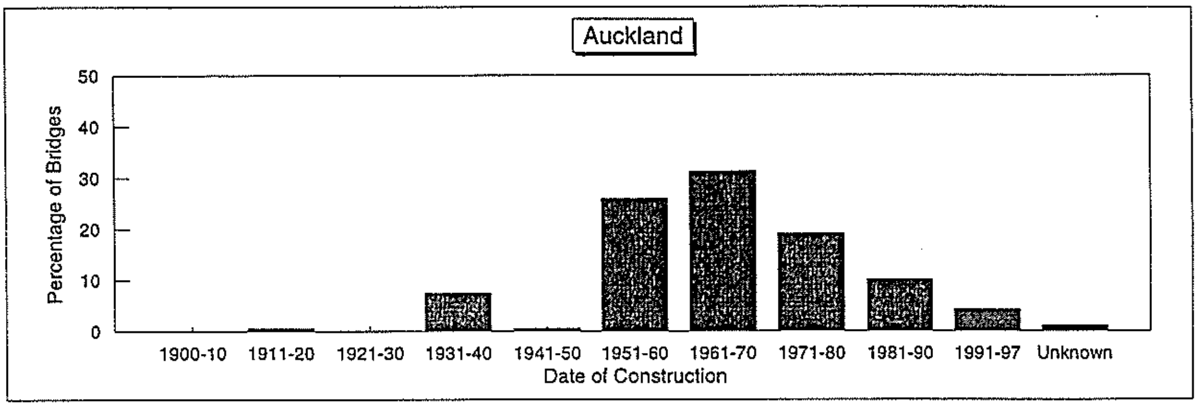
3.1.2 Age Distribution

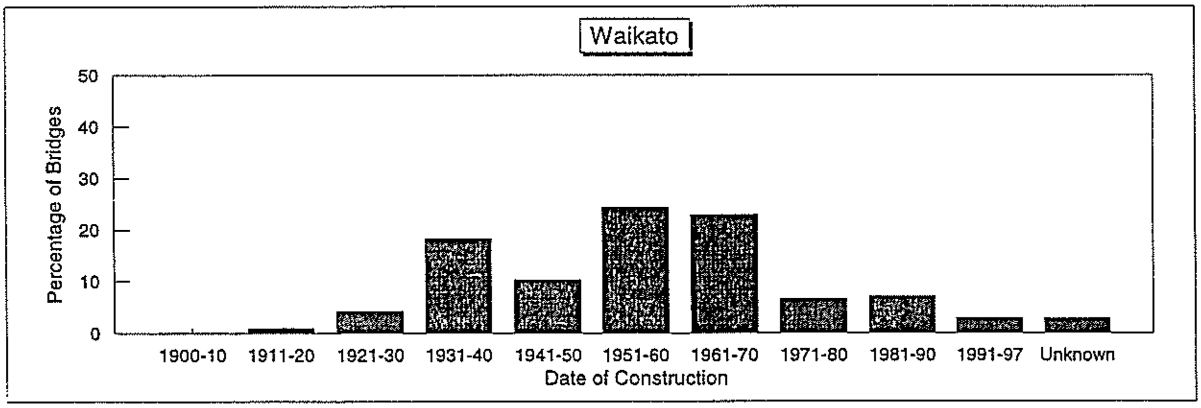
The age of the concrete bridges in each road district is presented in Figure 3.1, and the age distribution of all state highway bridges is presented in Figure 3.2.

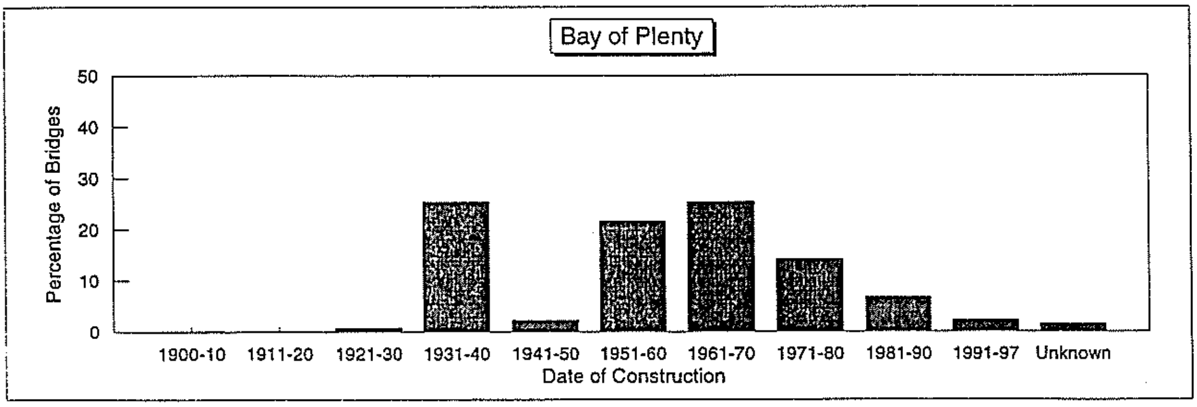
The histograms show some consistent trends in bridge construction ages between regions. In all regions, apart from Taranaki, the earliest major period of bridge construction was in either the 1920s or 1930s. In Taranaki a significant period of construction was between 1900 and 1920. In all regions there was a significant construction phase in the 1930s which accounts for 21% of all concrete bridges currently in use. Bridge construction then peaked in the 1950s and 1960s, accounting for 43% of all concrete bridges constructed. In Auckland fewer bridges were built in the 1930s than in the 1950s, 1960s and 1970s. This suggests that some of the 1930s bridges have been replaced there.

Figure 3.1 Construction dates of state highway bridges in each of the 14 Transit New Zealand road districts.









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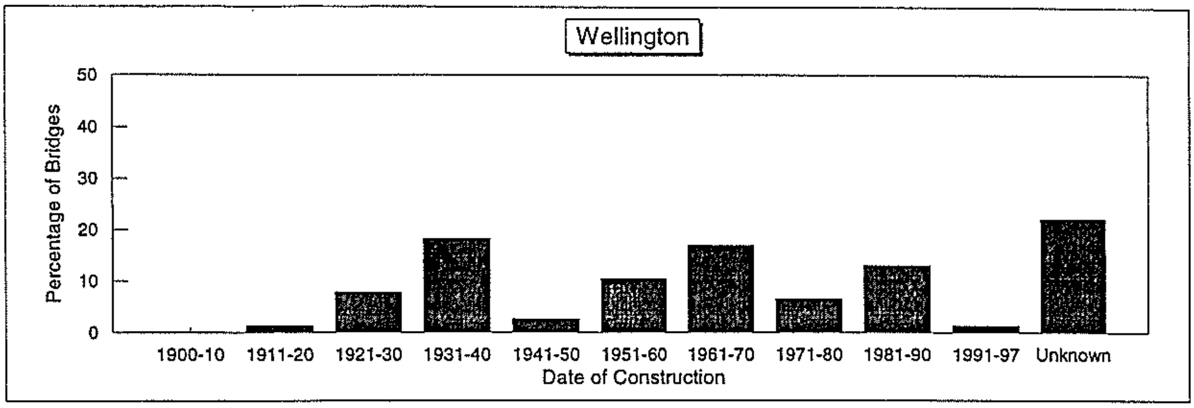

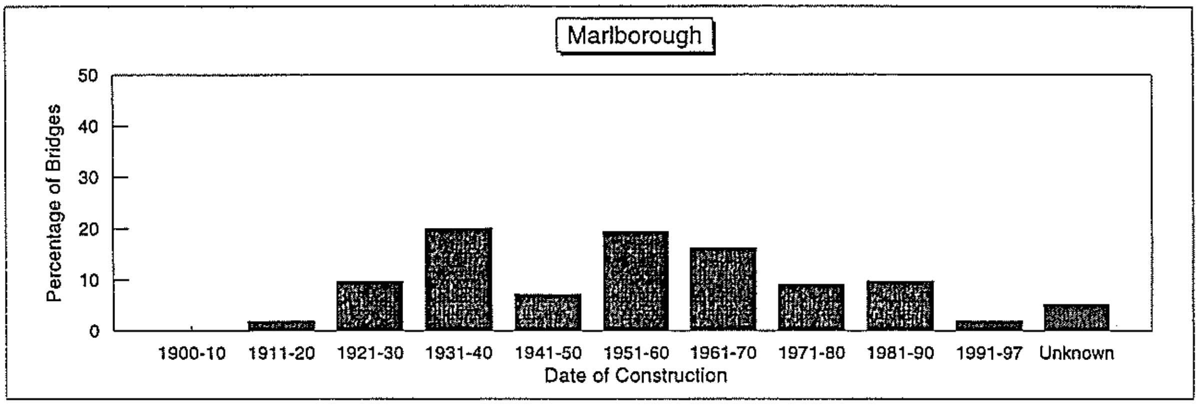

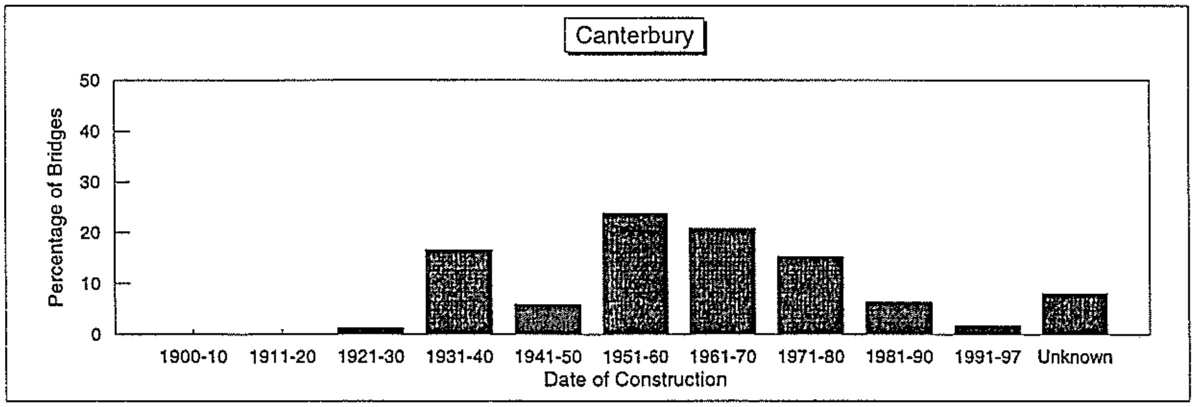

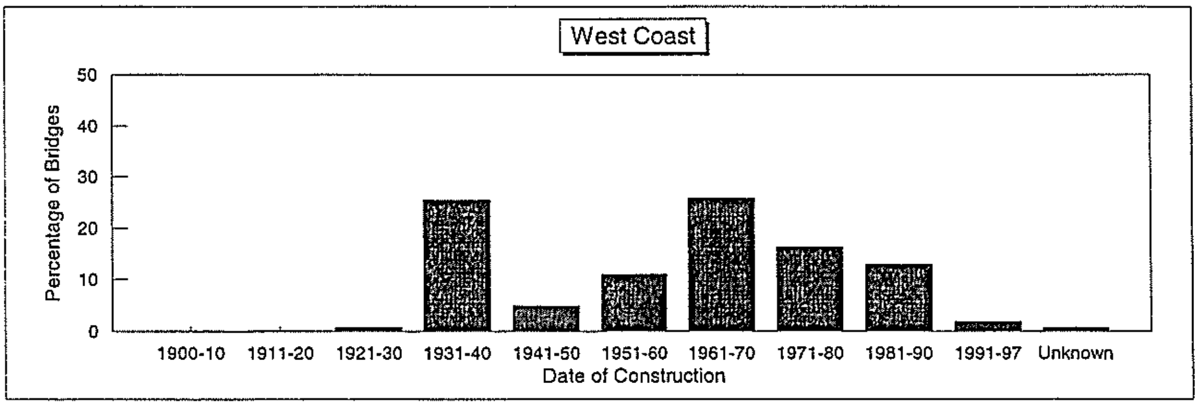

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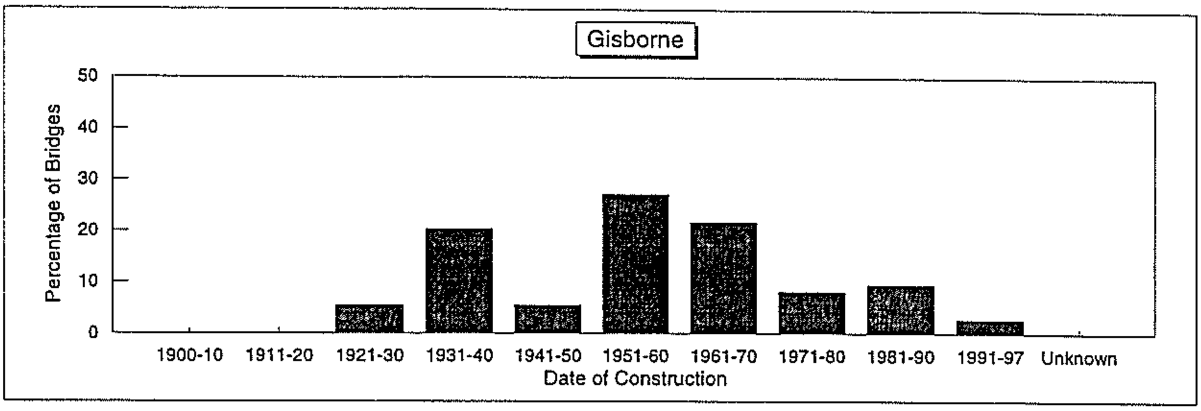

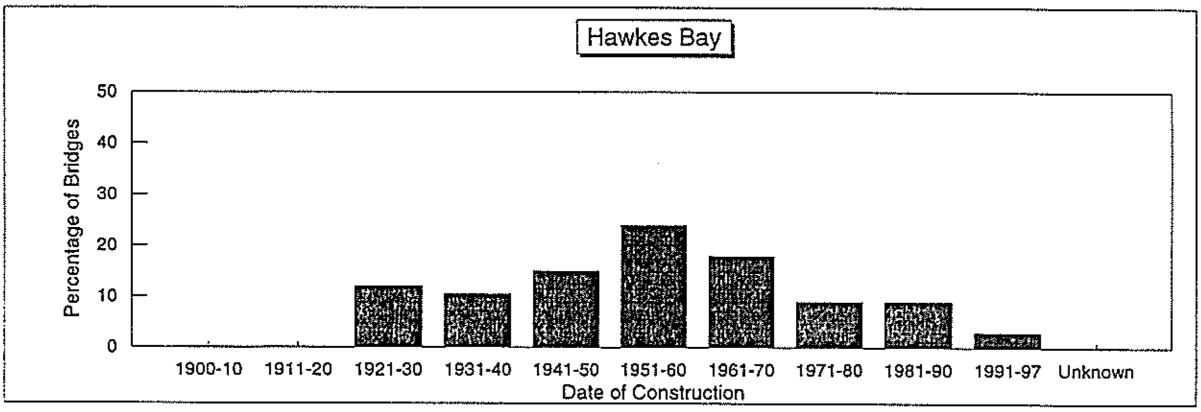

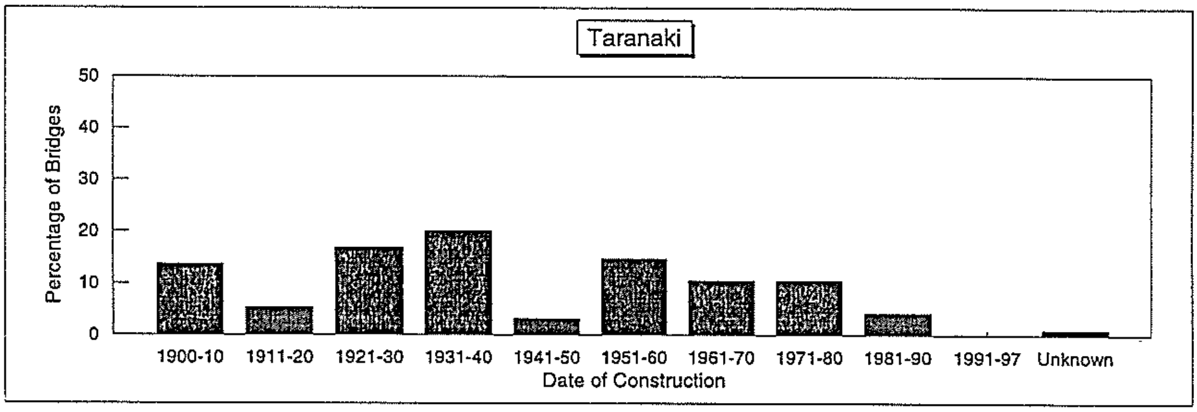

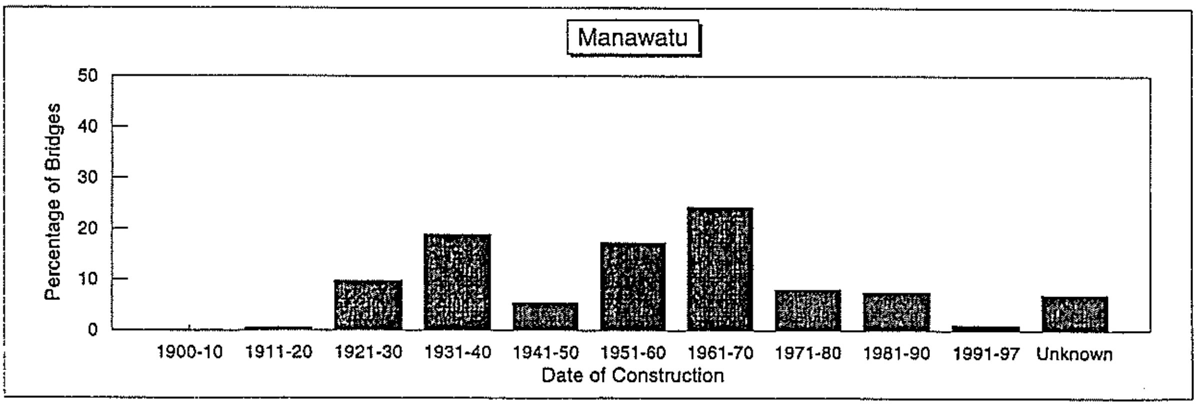

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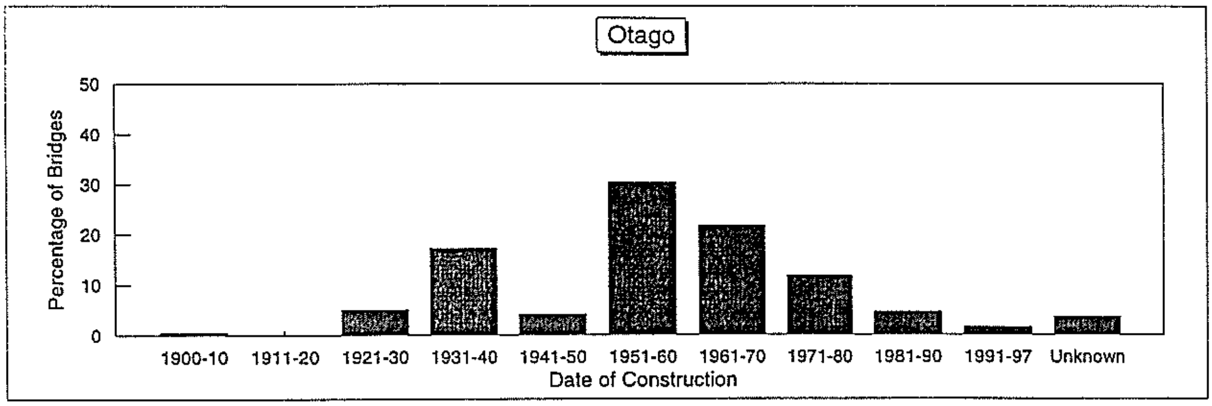


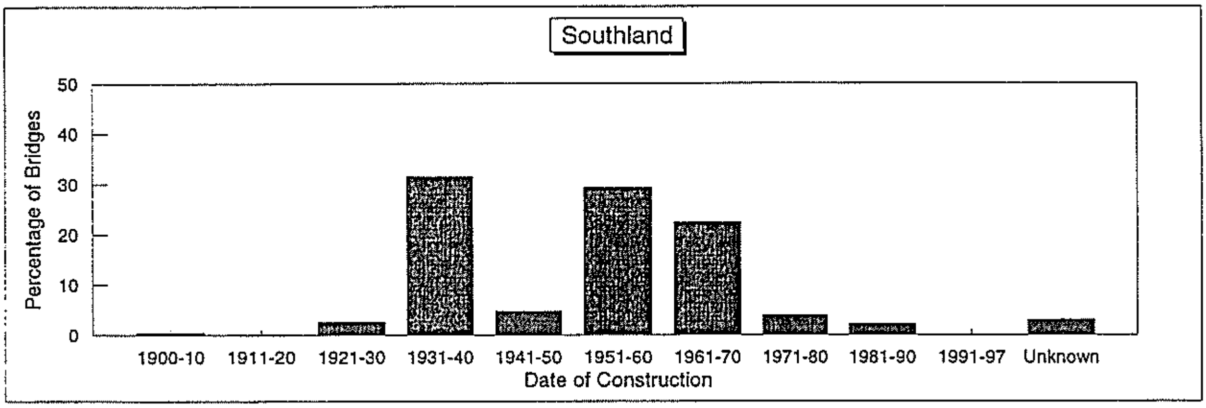
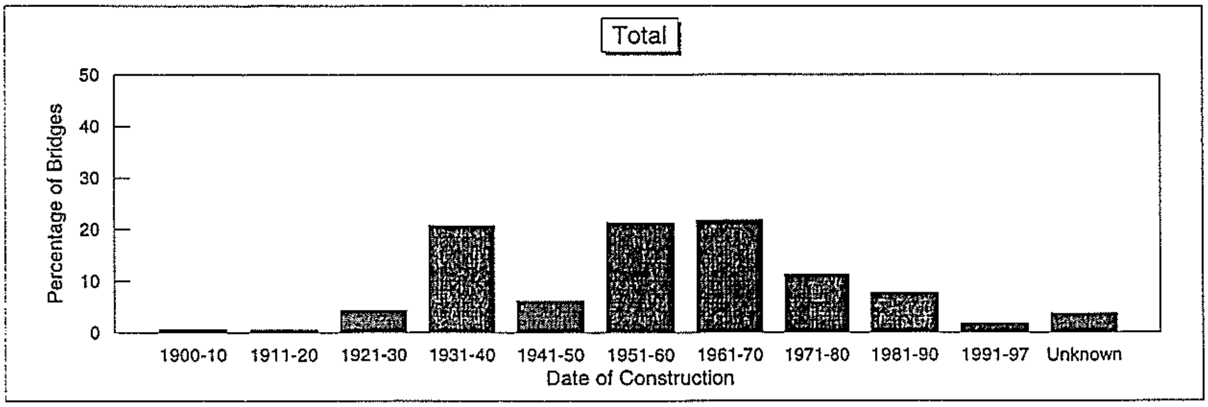


Figure 3.2 Construction dates of state highway bridges in all 7 Transit New Zealand regions.



Overall, 6% of bridges were built before 1930, 32% were built before 1950, and 43% were built between 1950 and 1970. Concrete bridge construction then declined, from 11% constructed in the 1970s and 8% in the 1980s, to approximately 2% in the 1990s (to 1997). The age of 4% of bridges is unknown.

3.1.3 Exposure Classifications for Reinforcement Corrosion

NZS 3101: Part 1: 1995 has established exposure classifications for members of concrete structures in above-ground exterior environments. These classifications are based on the risk of reinforcement corrosion induced by the ingress of chloride ions. By taking into account the prevailing wind and its intensity, the standard has established the boundary between "inland (A2)" and "coastal perimeter (B1)" exposure classifications. In Figure 3.3 these boundaries have been plotted on a map showing the Transit New Zealand road districts.

In specific situations bridges may be exposed to more corrosive environments. The "coastal frontage (B2)" exposure classification covers structures within 100 m of the high tide mark, or within 500 m of the high tide mark to the direction of a prevailing or other common wind. Bridges in close proximity to a coastline exposed to strong on-shore winds are likely to be in a coastal frontage zone. The most extreme corrosion environment is the "tidal/splash zone (C)" which may be encountered where piers are situated in a tidal estuary.

Figure 3.3 demonstrates the effect that a prevailing westerly weather pattern has on the exposure environments affecting the road districts. The districts with significant west-lying coastlines, i.e. Southland, West Coast, Manawatu/Wanganui, Taranaki, Waikato, Auckland and Northland, have wide coastal perimeter zones extending, in some cases, more than 30 km inland. In contrast, in road districts on the east coast the coastal perimeter zones are on average less than 5 km wide.

Local weather patterns are evident in Southland which has a wide coastal perimeter on the south coast due to strong on-shore winds, and in Northland and Auckland where an on-shore easterly wind prevails. The coastal perimeter zone in west coast road districts such as West Coast and Taranaki amounts to about 80% of the total land area, which is in contrast to east coast districts such as Canterbury and Hawke's Bay where the coastal area is less than 20%.

In Figure 3.4 the number of concrete bridges in the coastal exposure classifications (B1, B2, C) is compared to the total number of concrete bridges. A total 61% of the concrete bridges lie within these zones. In Northland, Auckland, Taranaki and West Coast districts, more than 90% of the concrete bridges are in the coastal zones. In several districts more bridges are near the coast than is indicated by land area, and this can be attributed to the concentration of the state highway network within the coastal perimeter. For example, in Canterbury more than 40% of bridges are located in the coastal perimeter although less than 20% of the land area is zoned as such.

Figure 3.3 Boundaries of state highway road districts and of zones of the NZS 3101:Part 1:1995 exposure classification.

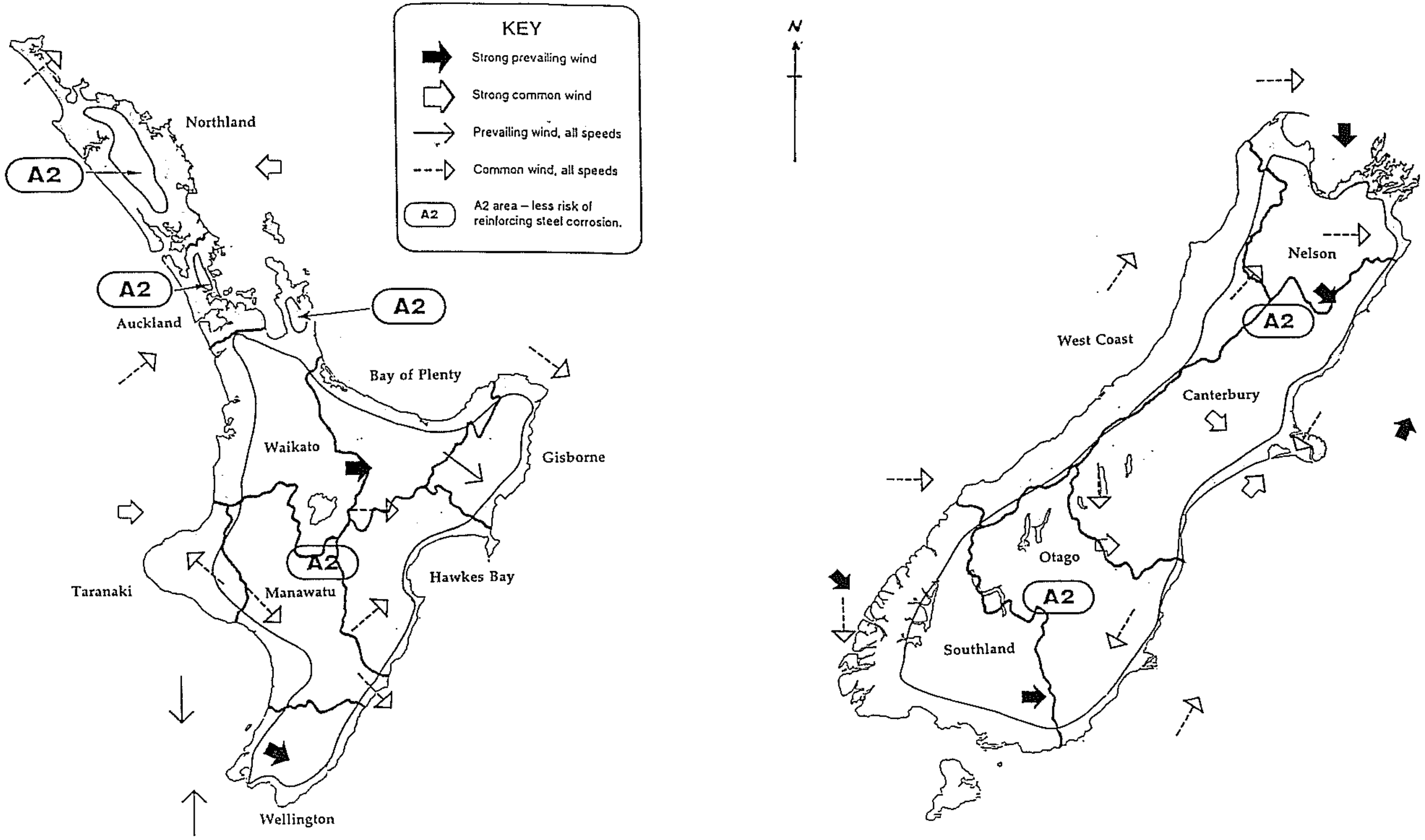
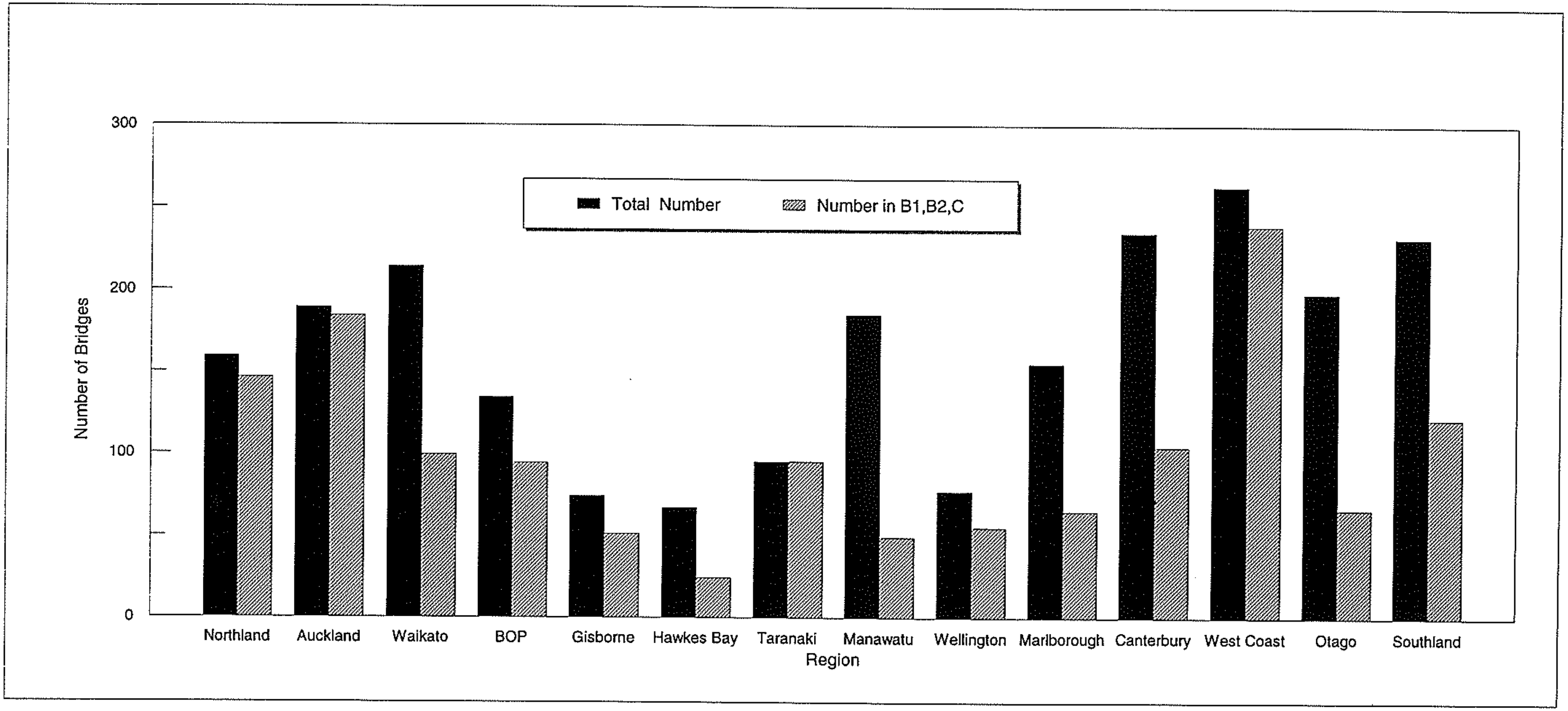


Figure 3.4 Number of concrete state highway bridges located in coastal exposure zones B1, B2 and C (as defined by NZS 3101 :1995).



3.1.4 Alkali Aggregate Reaction

The durability of New Zealand's concrete bridges may also be affected by alkali aggregate reaction (AAR). Aggregates from the volcanic regions of Taranaki and the Central Volcanic Plateau (Waikato and Manawatu/Wanganui regions) are known to be reactive, and AAR has been identified in state highway bridges in these regions (Freitag & Rowe 1990, Freitag 1994). AAR has also been identified in bridges in the Auckland region as a result of the use of sands from the Waikato River which contains volcanic material from the Central North Island.

Similar contamination is also present in the Rangitikei River (Doyle 1988). AAR was one of the contributing factors which led to the decision to replace the superstructure of one bridge on the Auckland Southern Motorway, and the cover concrete on the piers of a bridge on the Northwestern Motorway in Auckland. Apart from these, fewer than five bridges are known to have suffered more than just cosmetic damage caused by AAR.

3.1.5 Freeze-thaw

Minor freeze-thaw damage has been identified on bridges in the central North Island (Waikato and Manawatu/Wanganui regions) (Freitag & Rowe 1987) and might be expected to affect concrete bridges in the inland areas of the Canterbury, Otago and Southland Road Districts.

3.2 Local Authority Bridges

3.2.1 Number of Bridges

According to Transit New Zealand road statistics for the year ended 30 June 1996 (Transit New Zealand 1996), there are a total of 13,062 bridges and culverts on local roads, of which 57% are single lane structures. These structures are administered by 75 local authorities who individually manage a maximum of 875 (Southland District Council) and a minimum of 12 structures (Tauranga District Council).

The 19 local authorities who were surveyed administer a total of 5,808 bridges and culverts, and approximately 65% of this total are bridges with superstructures (beams and/or decks) constructed from cast-in situ or precast concrete. A breakdown of these totals for each local authority is presented in Table 3.2.

3.2.2 Age Distribution

The ages of concrete bridges currently administered by the local authorities are presented in Figures 3.5 and 3.6. Of the 19 authorities, 15 provided useful data on bridge ages, although several of these responses included a substantial number of "unknowns".

Figure 3.5 Construction dates of bridges administered by the 15 local authorities who responded with data on bridge ages.

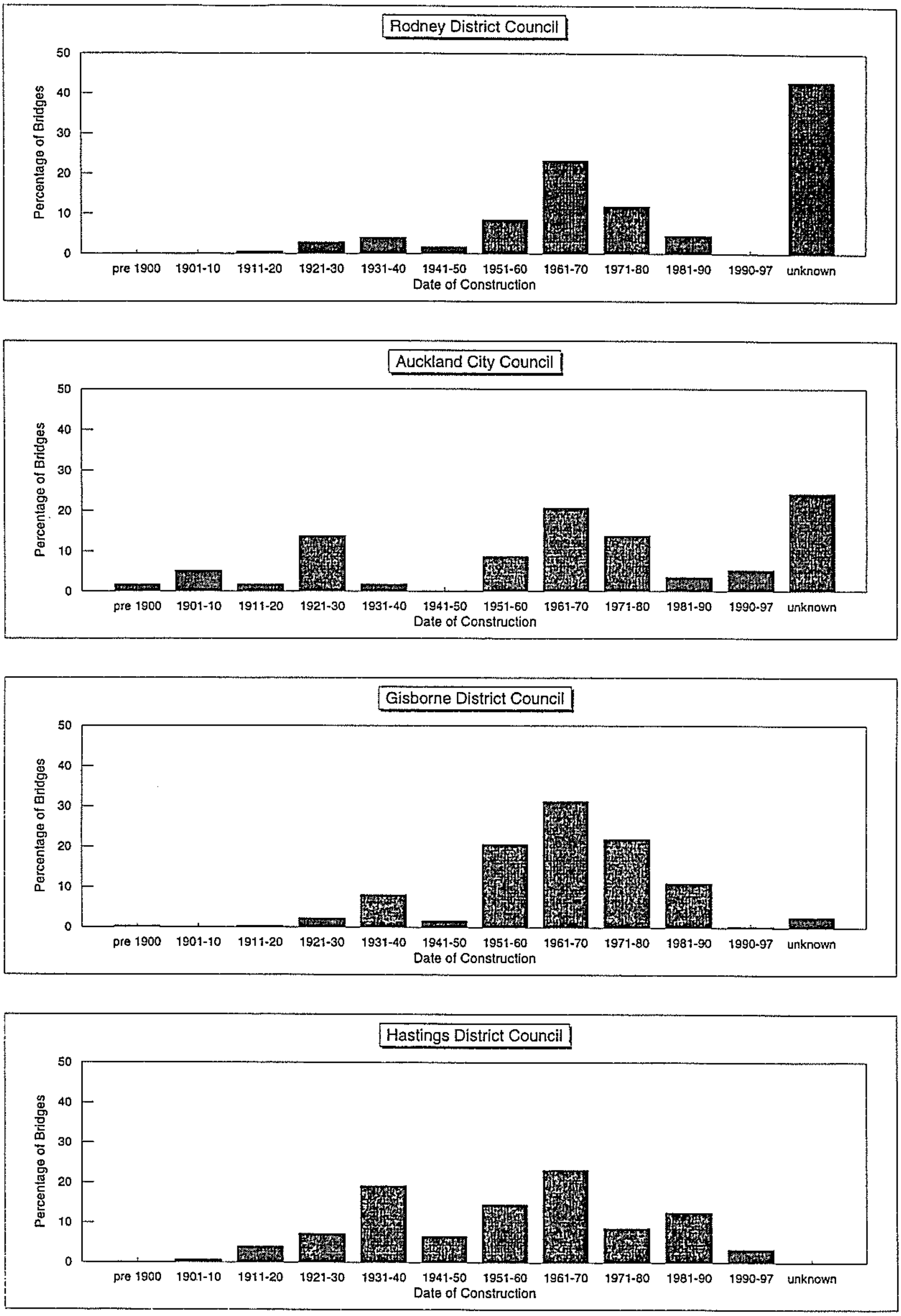
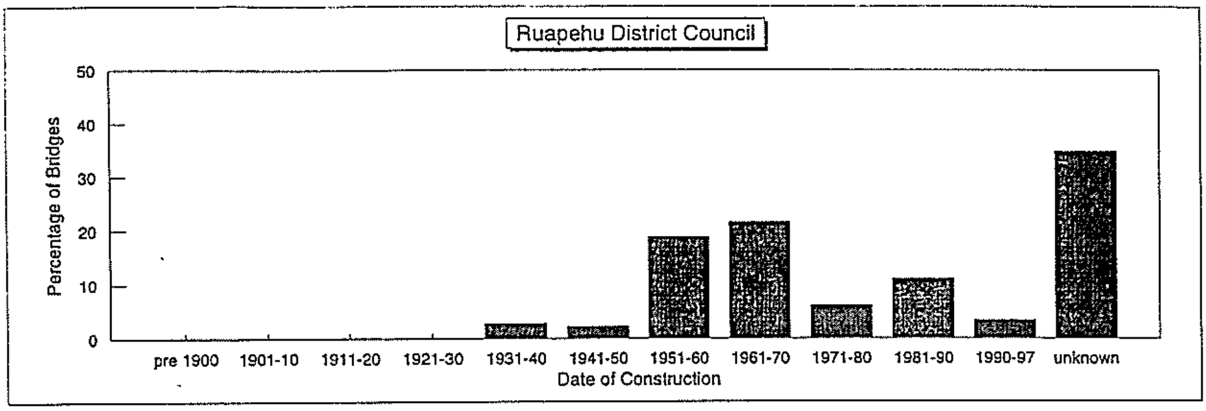
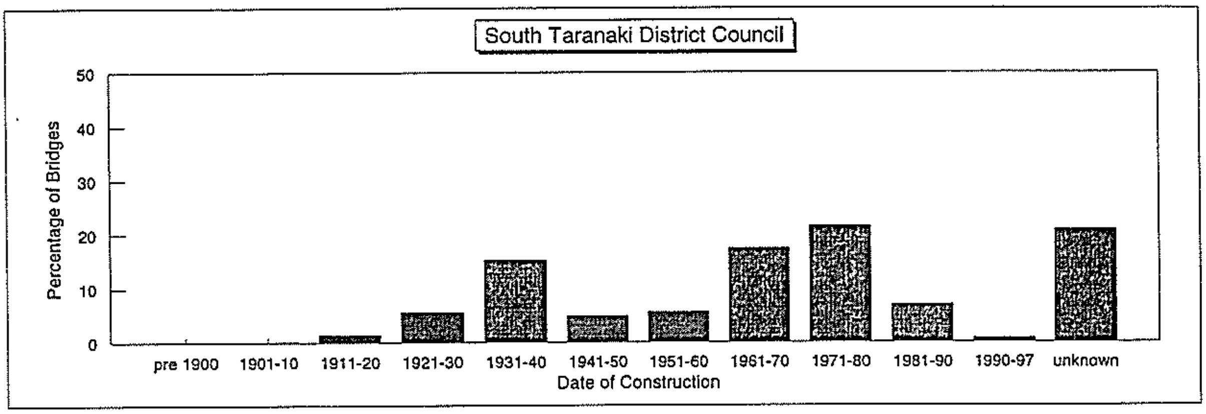
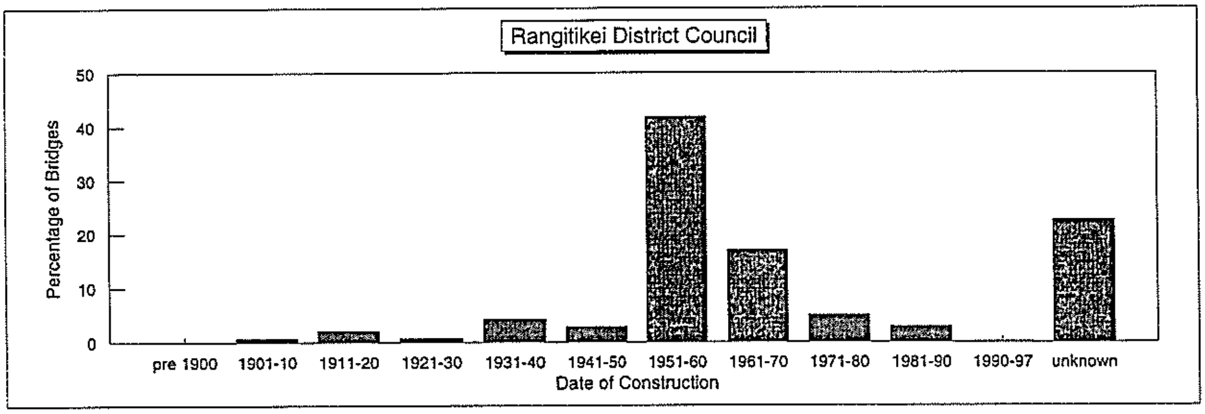


Figure 3.5 (continued)







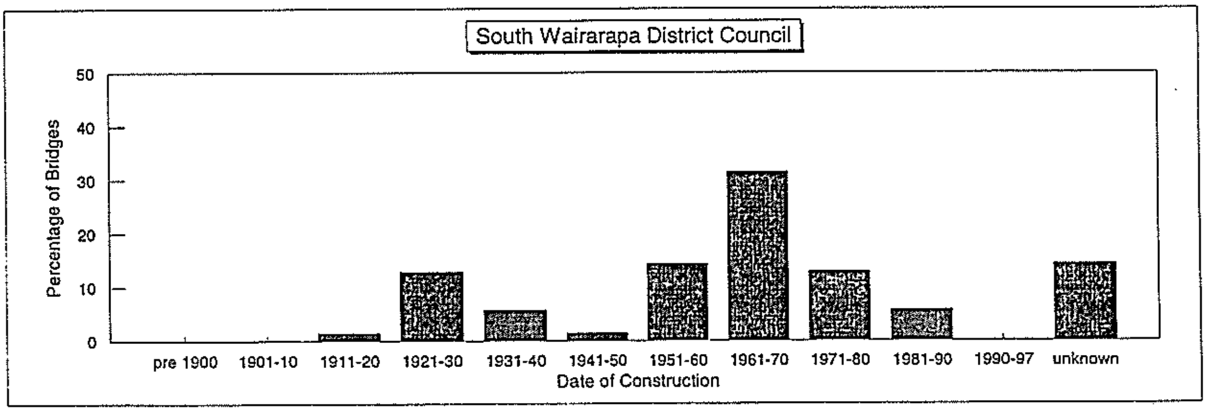
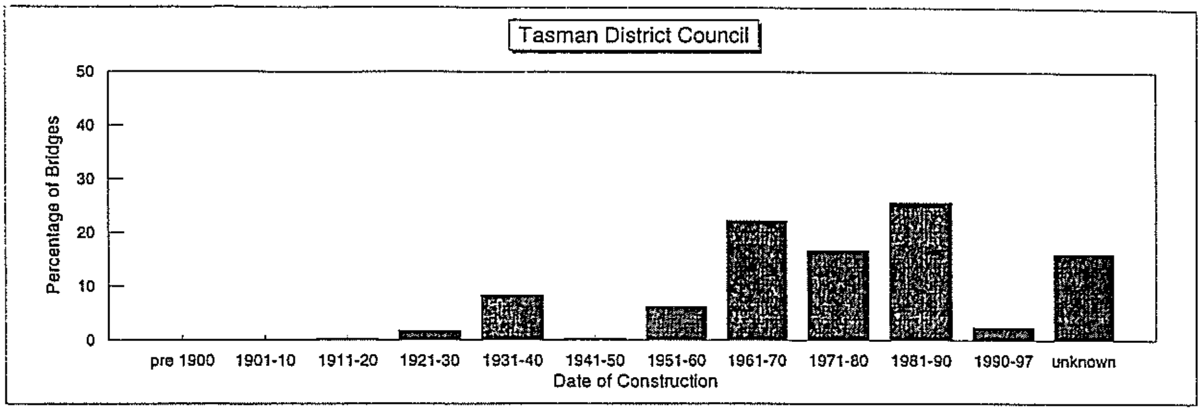
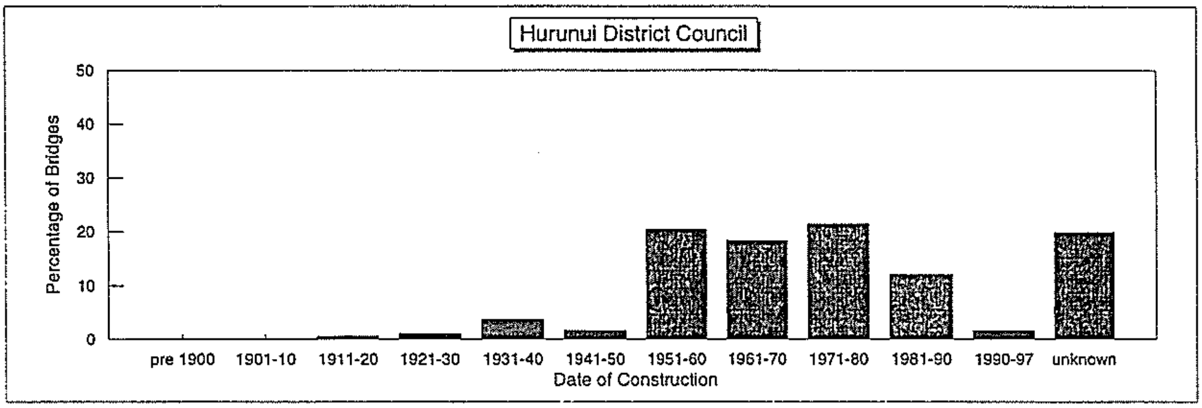
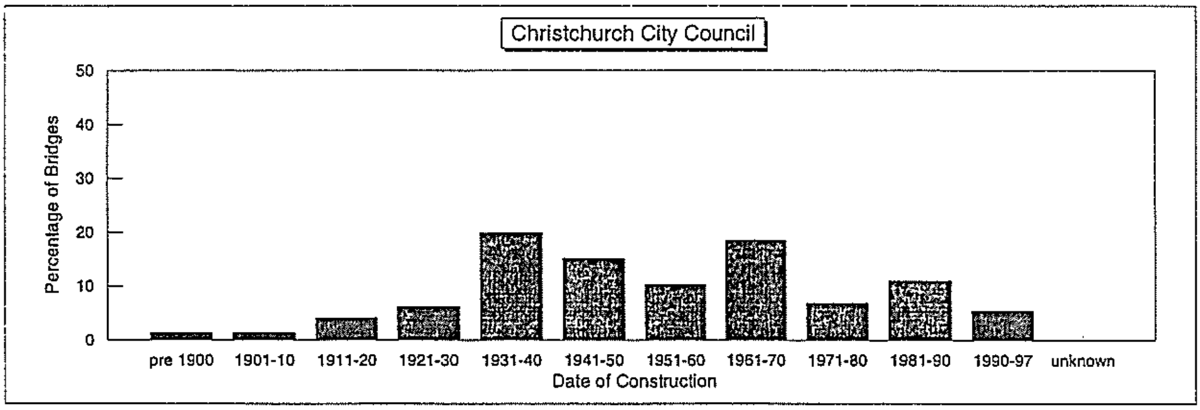


Figure 3.5 (continued)







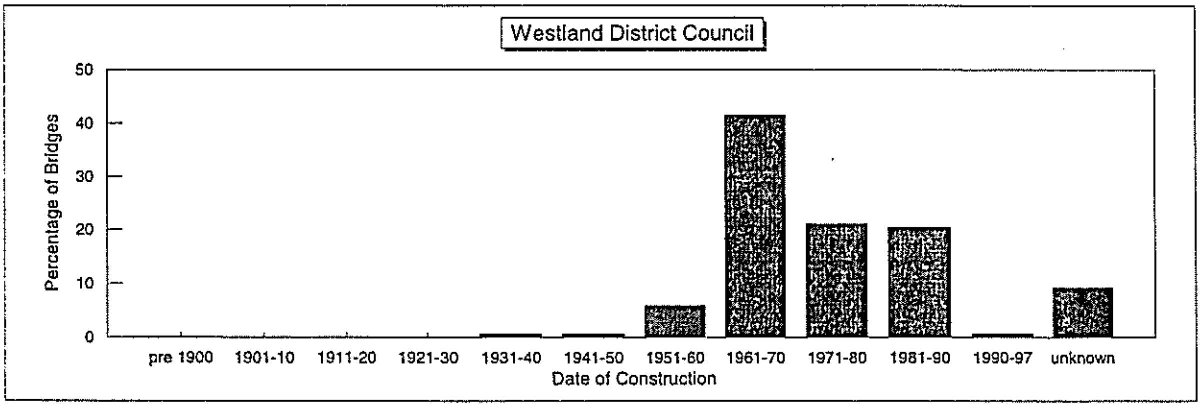
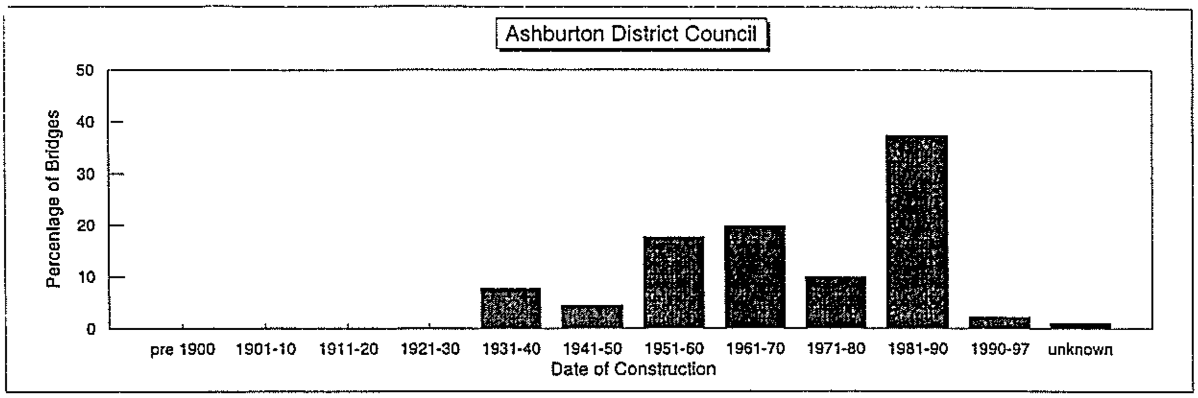
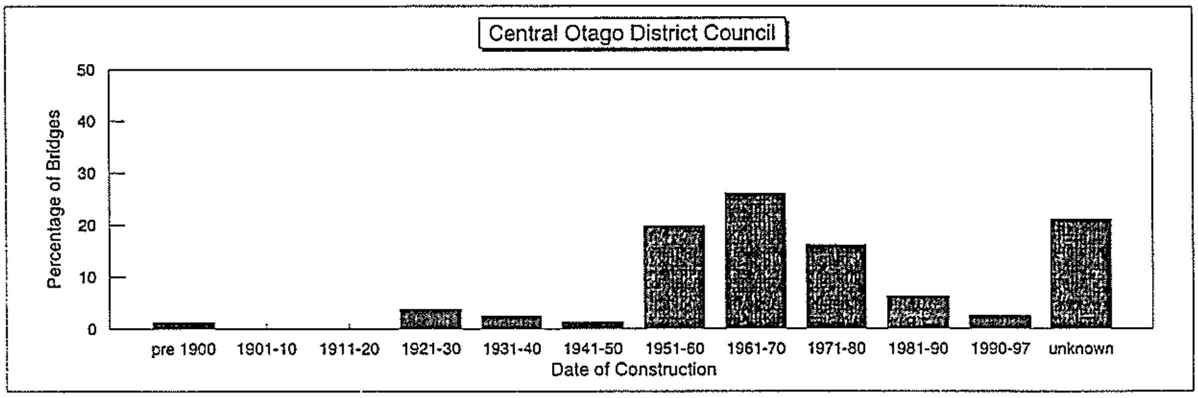


Figure 3.5 (continued)





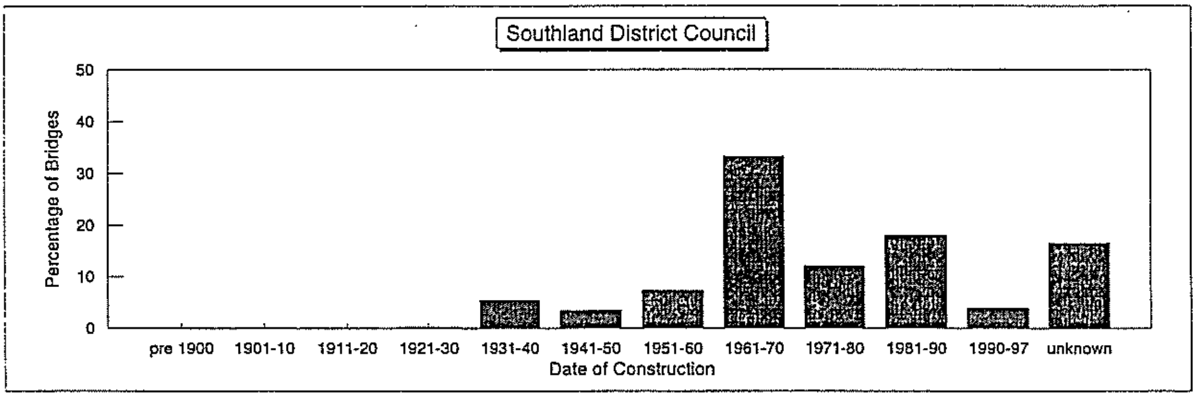


Figure 3.6 **Construction dates of bridges administered by all the 15 local authorities who responded with data on bridge ages.**

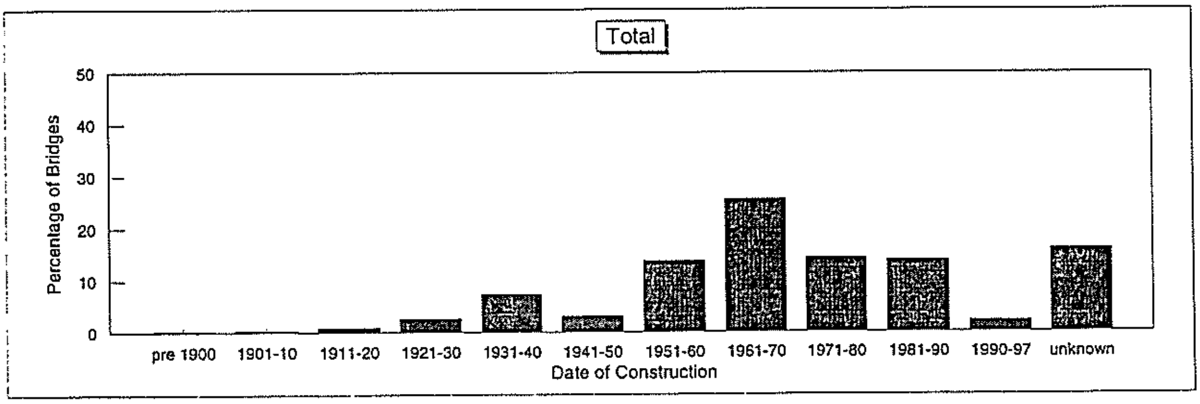


Table 3.2 Road bridges and culverts administered by 19 local authorities.

Local authority	No. of bridges and culverts	No. of bridges	No. of bridges with concrete superstructure*	No. of culverts
Far North	748[1]	627	494	121
Rodney	346[2]	247	181	-
Auckland	98[2]	66	58	-
Thames/Coromandel	142[1]	-	-	-
Gisborne	353[1]	-	306	-
Hastings	245[1]	203	151	42
Ruapehu	327[2]	-	188	31[3]
South Taranaki	223[1]	169	145	54
Rangitikei	209[1]	158	147	51
Tararua	466[2]	394	358	-
South Wairarapa	125[1]	86	70	39
Tasman	448[1]	-	291	71[3]
Hurunui	238[1]	209	194	29
Christchurch	242[1]	242	142	-
Banks Peninsula	169[1]	-	76	12[3]
Westland	269[1]	-	156	-
Ashburton	116[1]	111	96	5
Central Otago	169[1]	-	81	-
Southland	875[2]	-	473	102[3]

* Concrete superstructure - beams and/or deck constructed of cast-in situ or precast concrete.

[1] Data supplied by local authority.

[2] Data from Transit New Zealand Roading Statistics to 30 June 1996.

[3] Concrete culverts only. – data not supplied.

All local authorities surveyed had had a major construction period in the 1960s but otherwise there are no clear trends. Several local authorities reported significant numbers of bridges built before 1930. Bridges in Auckland City, Christchurch City and Hastings District have a fairly even age distribution, while other local authorities had more concentrated bridge building periods.

Of the bridges of known age, 4% were built before 1930, and 14% were built before 1950. The peak decade of bridge construction was the 1960s, which accounts for 25% of all concrete bridges. Other significant bridge building phases were in the 1950s, 1970s and 1980s, and these four decades account for 68% of the total bridges, and 30% of concrete bridges were constructed after 1970. Bridges with "unknown" ages account for 17% of the bridge stock administered by these 15 authorities.

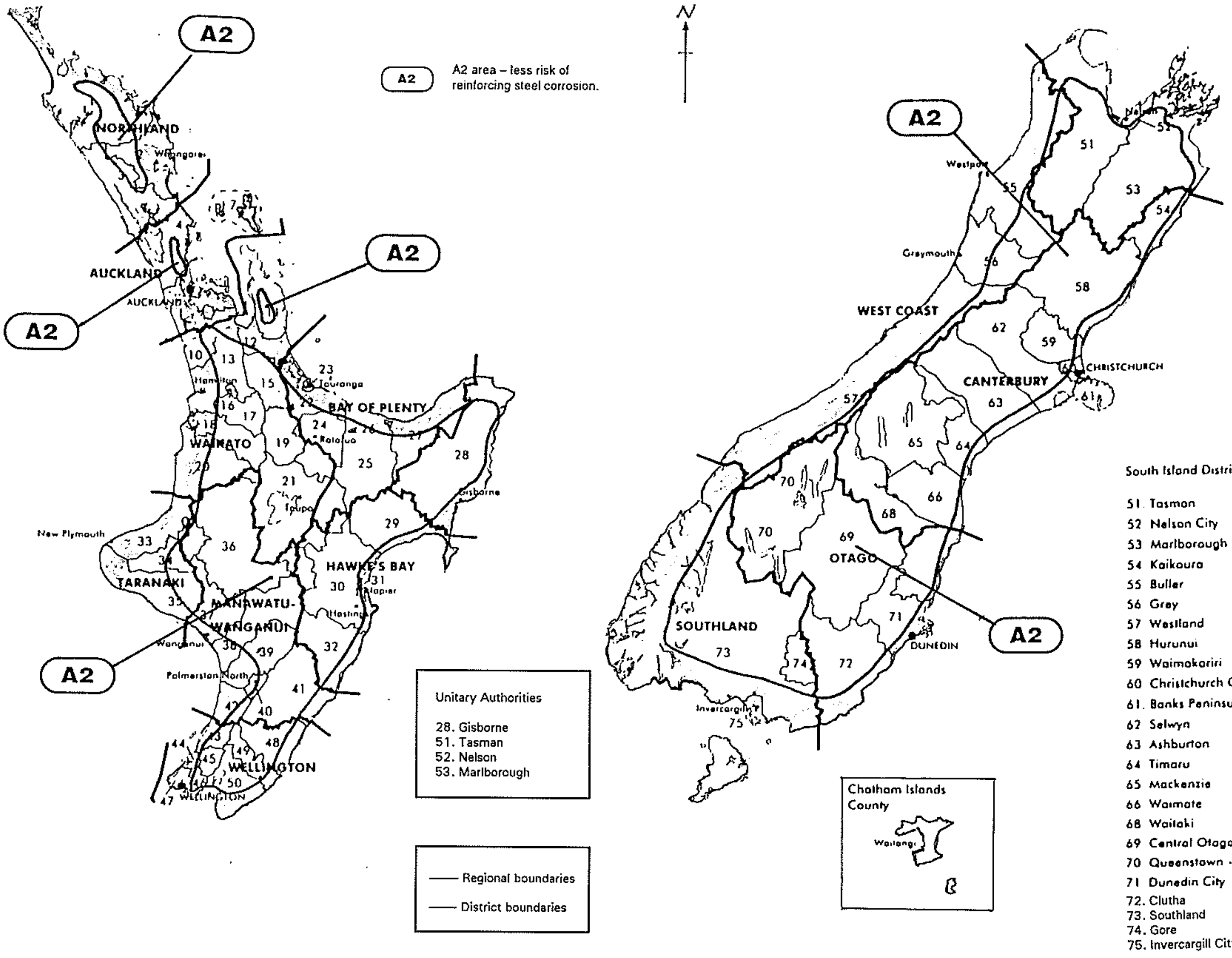
3.2.3 Exposure Classifications for Reinforcement Corrosion

In Figure 3.7 the boundaries between the NZS 3101 inland and coastal exposure classifications are superimposed on a map of local authority boundaries. As discussed in Section 3.1 of this report, the exposure classifications are affected by a prevailing westerly weather pattern so that there is a broad coastal perimeter zone along the west coast of both islands. The land areas administered by local authorities are smaller than the national road districts and so some lie completely within one exposure zone.

Figure 3.7 **Boundaries of local authority districts and of the zones of the NZS 3101: Part 1:1995 exposure classification.**

North Island Districts

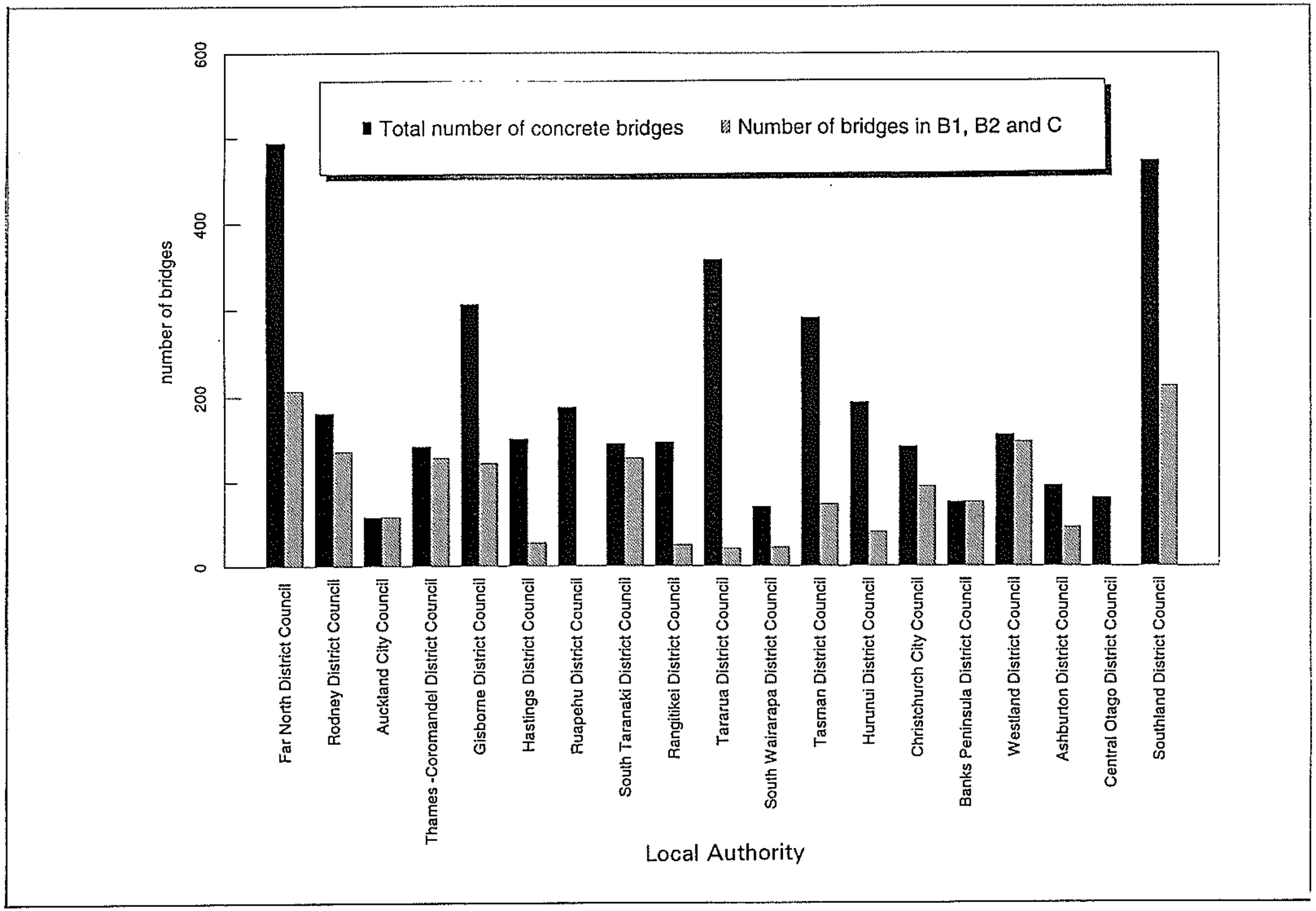
1. Far North
2. Whangarei
3. Kaipara
4. Rodney
5. North Shore City
6. Waitakere City
7. Auckland City
8. Manukau City
9. Papakura
10. Franklin
11. Thames - Coromandel
12. Hauraki
13. Waikato
15. Matamata - Piako
16. Hamilton City
17. Waipa
18. Otorohanga
19. South Waikato
20. Waitomo
21. Taupo
22. Western Bay of Plenty
23. Tauranga
24. Rotorua
25. Whakatane
26. Kawerau
27. Opotiki
28. Gisborne
29. Wairoa
30. Hastings
31. Napier City
32. Central Hawke's Bay
33. New Plymouth
34. Stratford
35. South Taranaki
36. Ruapehu
37. Wanganui
38. Rangitikei
39. Manawatu
40. Palmerston North City
41. Tararua
42. Horowhenua
43. Kapiti Coast
44. Porirua City
45. Upper Hutt City
46. Hutt City
47. Wellington City
48. Masterton
49. Carterton
50. South Wairarapa



South Island Districts

51 Tasman
52 Nelson City
53 Marlborough
54 Kaikoura
55 Buller
56 Grey
57 Westland
58 Hurunui
59 Waimakariri
60 Christchurch City
61. Banks Peninsula
62 Selwyn
63 Ashburton
64 Timaru
65 Mackenzie
66 Waimate
68 Waitaki
69 Central Otago
70 Queenstown - Lakes
71 Dunedin City
72. Clutha
73. Southland
74. Gore
75. Invercargill City

Figure 3.8 Number of concrete local authority bridges located in coastal exposure zones B1, B2 and C (as defined by NZS 3101:1995).



Areas such as South Waikato, Taupo, Ruapehu, MacKenzie, Queenstown-Lakes and Central Otago have an entirely inland exposure classification, while other local authorities such as Auckland City, Hauraki, Franklin, New Plymouth, Westland and Banks Peninsula are almost entirely within the coastal perimeter.

In Figure 3.8 the number of local authority concrete bridges in the coastal exposure classifications (B1, B2, C) is compared to the total number of concrete bridges. Local authority roads are widely spread within the habitable area of each local authority so are less concentrated in the coastal fringe than the state highway network. Concrete bridges that are located within the coastal zones comprise 45%. In Auckland, Banks Peninsula and Westland over 90% of concrete bridges are within the coastal zone. Ruapehu and Central Otago have no bridges in this zone.

3.2.4 AAR and Freeze-thaw

The durability of concrete bridges administered by local authorities may also be affected by AAR and freeze-thaw attack as discussed in Section 3.1 of this report.

4. POSTAL SURVEY

4.1 Introduction

Twenty three responses were received from the questionnaires sent to the 25 road controlling authorities. One Transit New Zealand region did not reply, and another provided a response from each of two districts within the region. Two local authorities did not reply. Results from the survey are presented question-by-question in the following sections.

While the local authorities were selected to cover a range of environments, the bridges administered by these authorities might not accurately represent the total bridge stock in the country. For example, local authorities administering fewer than 100 bridges might take a different approach to those with a larger number. Consequently the results cannot necessarily be extrapolated to the whole bridge stock.

Individual respondents were identified when analysing the data but are not identified in this report. Thus statements such as "10 different respondents reported that random cracking affected more than 20% of bridges" (Section 4.3) cannot be substantiated from the data in the accompanying table because some of the respondents' bridges might appear in both the pre-1960 and post-1960 age groups. Similarly, relationships between responses and the proportion of a respondent's bridges which are in a coastal environment cannot be substantiated from the data presented because the individuals' responses are not identified.

In several of the questions responses were sought for both pre-1960 and post-1960 bridges. 1960 was arbitrarily chosen to separate "early" construction which was dominated by cast-in situ concrete from "later" construction which included an increasing number of precast elements. Effects of age are sometimes discussed in terms of bridges built more than 50 years ago, i.e. before 1950. This is an attempt to relate observation to the 50-year design life specified by NZS 3101:1995, the New Zealand standard for concrete construction.

4.2 Incidence of Design- and Construction-Related Defects (Question 1)

Design- and construction-related defects which affect the durability of concrete bridges include voids in the concrete (honeycombing), deck joints and drainage ports which discharge water onto the sub-structure, uniformly distributed linear cracks on deck soffits which can indicate inadequate reinforcement design, concrete mix design or curing, and lack of effective dripformers to drain the water off deck soffits. These defects were more common in bridges built before 1960 but have not been entirely eliminated from newer bridges, as shown in Table 4.1 and Figure 4.1.

Figure 4.1 **Frequency of design- and construction-related defects based on period of construction (pre-1960 and post-1960).**

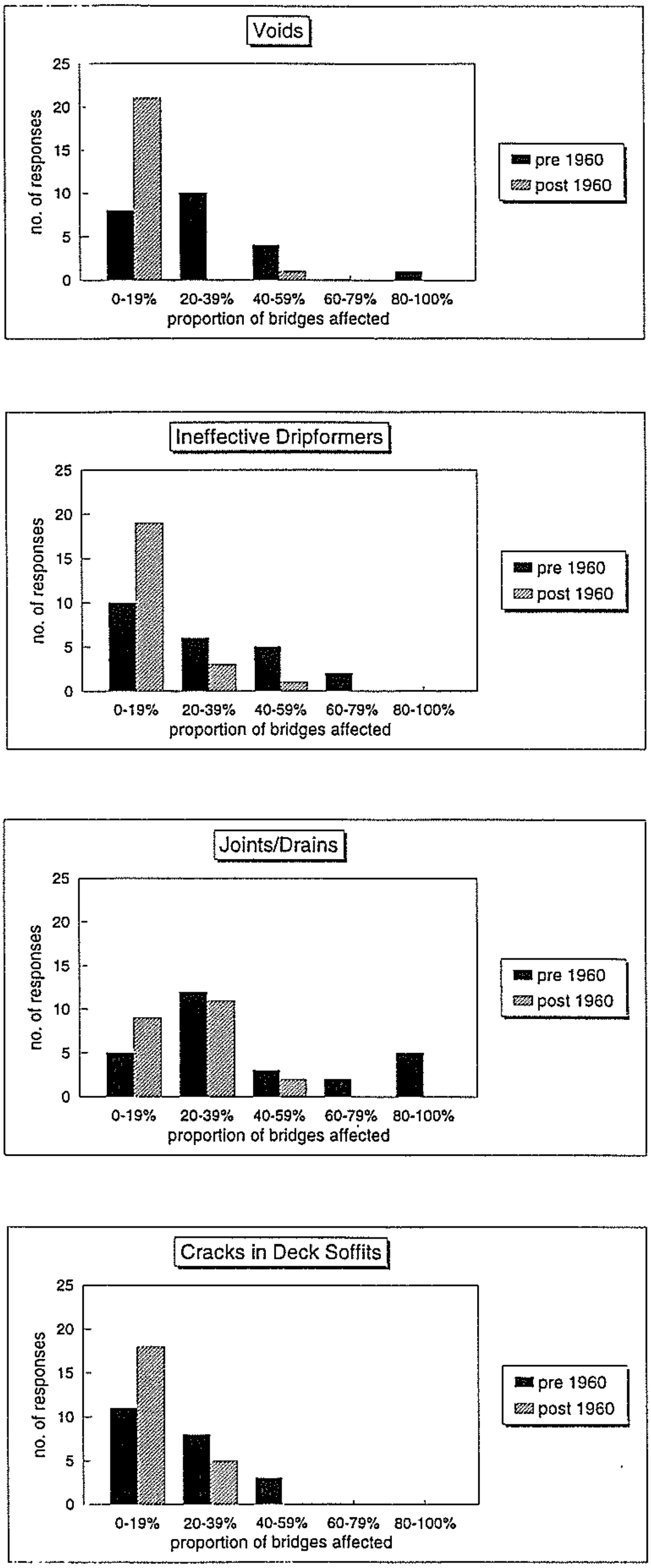


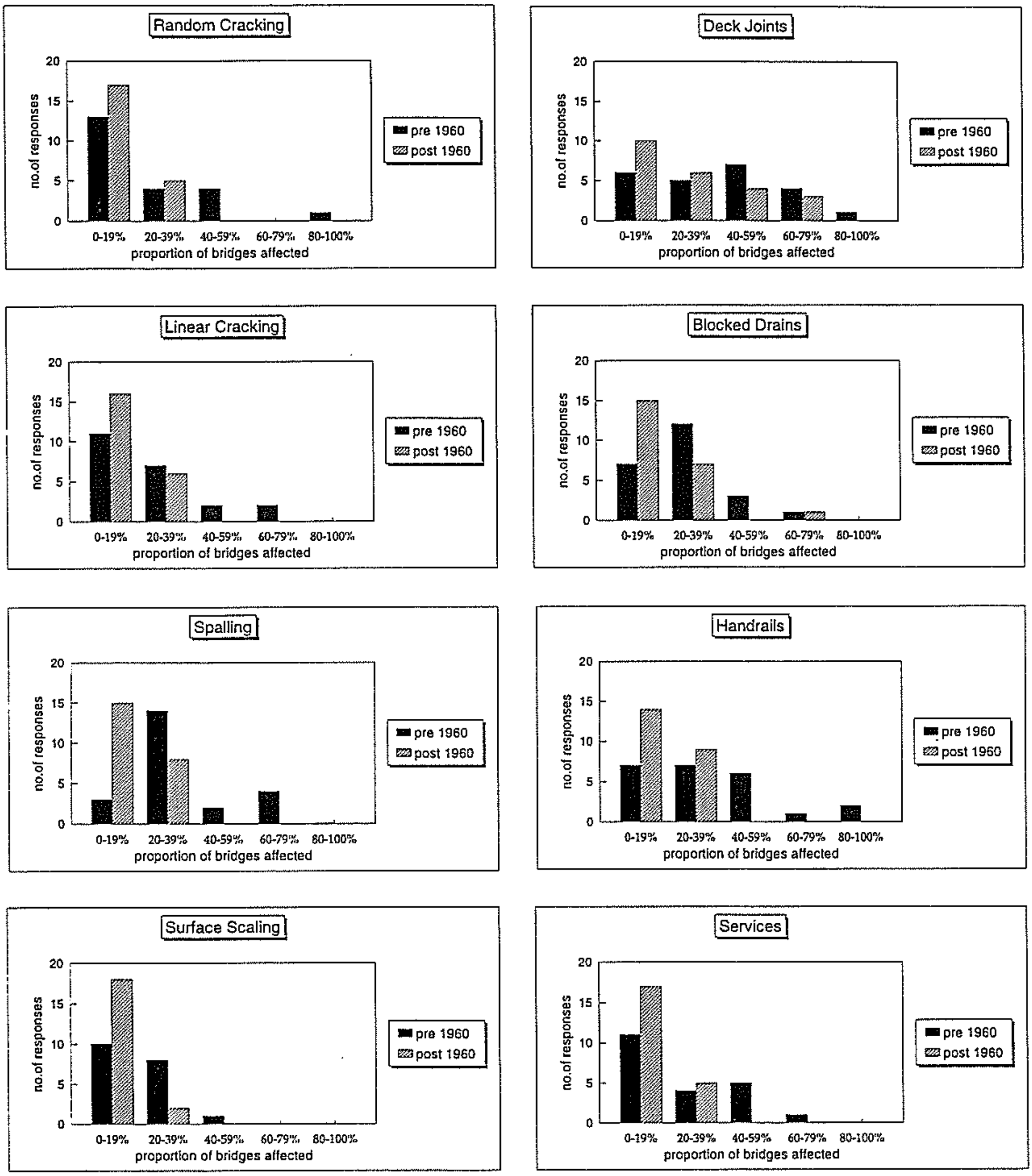
Table 4.1 Frequency of design- and construction-related defects based on period of construction (pre-1960, post-1960).

Defect	Age	Proportion of bridges affected (number of responses)					
		Don't know	**0-19%**	**20-39%**	**40-59%**	**60-79%**	**80-100%**
Voids in concrete	Pre-1960	0	8	10	4	0	1
	Post-1960	1	21	0	1	0	0
Ineffective dripformers	Pre-1960	0	10	6	5	2	0
	Post-1960	0	19	3	1	0	0
Joints/drains directing water onto concrete	Pre-1960	0	5	12	3	2	1
	Post-1960	1	9	11	2	0	0
Cracks in deck soffits	Pre-1960	1	11	8	3	0	0
	Post-1960	0	18	5	0	0	0

Table 4.2 Frequency of durability problems based on period of construction (pre-1960, post-1960)

Problem	Age	Proportion of bridges affected (number of responses)					
		Don't know	**0-19%**	**20-39%**	**40-59%**	**60-79%**	**80-100%**
Random cracking	Pre-1960	1	13	4	4	0	1
	Post-1960	0	17	5	0	0	1
Linear cracking	Pre-1960	1	11	7	2	2	0
	Post-1960	1	16	6	0	0	0
Spall	Pre-1960	0	3	14	2	4	0
	Post-1960	0	15	8	0	0	0
Surface scaling	Pre-1960	4	10	8	1	0	0
	Post-1960	3	18	2	0	0	0
Deck joint problems	Pre-1960	0	6	5	7	4	1
	Post-1960	0	10	6	4	3	0
Blocked drain	Pre-1960	0	7	12	3	1	0
	Post-1960	0	15	7	0	1	0
Handrails	Pre-1960	0	7	7	6	1	2
	Post-1960	0	14	9	0	0	0
Services	Pre-1960	2	11	4	5	1	0
	Post-1960	0	17	5	0	1	0

Figure 4.2 Frequency of durability problems based on period of construction (pre-1960, post-1960).



4.3 Incidence of Durability Problems (Question 2)

Common durability problems on concrete bridges include random cracking (structural cracks, surface crazing, sulphate attack, alkali aggregate reaction), linear cracking (thermal cracking, drying shrinkage), reinforcement corrosion, surface scaling (absorption and evaporation of salt solutions, chemical attack, freeze-thaw), poorly performing deck joints, blocked drains, handrail damage, and problems related to services attached to the bridge (e.g. corrosion of fasteners, ponding, accumulation of debris). These problems were more common in bridges built before 1960, as shown in Table 4.2 and Figure 4.2. However they do still occur on newer bridges. In particular, problems with deck-joint performance are almost as common on bridges built since 1960.

Ten different respondents reported that random cracking affected more than 20% of bridges in one or both age groups. They include five of the ten believed to administer bridges that are likely to be affected by AAR.

Eleven different respondents reported that linear cracking affected more than 20% of bridges. There is no obvious pattern to these responses, although they include only one of eight South Island respondents compared to ten out of fifteen from the North Island. This could reflect a greater incidence of drying shrinkage in the North Island, which in turn could result from the type of aggregate used.

The risk of spalling caused by corroding reinforcement increases with age because the problem takes time to develop, and the protection afforded by the cover concrete is often reduced by construction defects, which are more common in older bridges. Exposure to salt from seawater also increases the risk of corrosion.

The relationship between spalling, bridge age and coastal exposure that is evident from the responses to this question is demonstrated by the data in Table 4.3.

Table 4.3 Relationship between spalling, bridge age and coastal exposure.

% of bridges affected by spalling	**<20**		**≥20**	
% of bridges in the region/ district which are in coastal exposure zones	**<50**	**≥50**	**<50**	**≥50**
pre-1960 (no. of respondents)	1	2	13	7
post-1960 (no. of respondents)	11	4	3	5

All but three respondents claimed that more than 20% of their pre-1960 bridges were affected by spalling. Two of the three have more than half their bridges in the coastal exposure zones. Of the 20 who said that more than 20% of pre-1960 bridges were affected, 13 have less than 50% of their bridges in the coastal exposure zones. For the older bridges, it seems therefore that spalling is not necessarily related to proximity to the coast. This suggests that, for older structures, construction defects are the predominant factor in determining corrosion risk. Eight different respondents said that more than 20% of their post-1960 bridges were affected by spalling. Five of these have more than half their bridges in the coastal exposure zone. Of the 15 who said that less than 20% of their bridges were affected, 11 have less than half their bridges in the coastal exposure zone. Thus for newer bridges, which have fewer construction defects, the risk of spalling increases with proximity to the coast.

Nine different respondents reported surface scaling on more than 20% of bridges in one or both age groups. They include five of the nine regions/districts likely to have bridges affected by frost. Three of the remaining four respondents have more than half their bridges in the coastal exposure zones. The scaling reported is therefore probably caused by freeze-thaw attack or salt. Three respondents representing regions/districts which might be affected by scaling did not know whether their bridges were affected, so the actual incidence might be higher than the responses suggest.

Sixteen different respondents reported problems with handrails in more than 20% of bridges in one or both age groups. There is no obvious relationship between the age distribution or exposure condition of their bridges and the higher incidence of handrail problems.

Ten different respondents reported problems related to services attached to bridges. All but one of these was from the North Island, and all but one have more than half their bridges in the coastal exposure zone. Without knowing what the specific problems are it is not possible to judge whether this is significant.

4.4 Distribution of Durability-Related Problems (Question 3)

Table 4.4 and Figures 4.3 and 4.4 show the distribution of durability-related problems with age, type of construction and proximity to the coast.

Deck joint problems were reported to be particularly common in bridges of all ages, locations and type.

Durability problems appear to affect cast-in situ bridges more than those containing precast or prestressed elements.

For cast-in situ bridges some defects were considered more common in older bridges (random cracking, spalling, blocked drains, handrail deterioration) while others presented similar problems on bridges in both age groups (linear cracking, surface scaling, erosion, and attached services). Age has less effect on the durability of bridges containing precast elements, although problems with deck joints and services are slightly more common in post-1960 bridges.

Spalling caused by reinforcement corrosion was considered by the respondents to be more common on coastal bridges than on those inland, reflecting the influence of chloride ion contamination by seawater. This effect is more marked for pre-1960 bridges than for those built after 1960. Note that the opposite effect was indicated by the responses to question 2.

On pre-1960 bridges surface scaling and blocked drains are slightly more prevalent on inland bridges. Scaling is therefore likely to be a result of frost as suggested by the response to question 2 (Section 4.3 of this report). The presence of other defects was not influenced by proximity to the coast.

Table 4.4 Distribution of durability problems based on period of construction (pre-1960, post-1960).

Problem	Age	Frequency (number of responses)				
		Cast	Cast/ prestressed	Precast prestressed	Coast	Inland
Random cracking	Pre-1960	10	0	0	7	8
	Post-1960	6	2	0	5	6
Linear cracking	Pre-1960	8	1	0	8	9
	Post-1960	7	1	0	5	6
Spalling	Pre-1960	16	1	1	17	7
	Post-1960	6	1	1	5	3
Surface scaling	Pre-1960	5	0	0	3	6
	Post-1960	4	0	0	3	3
Deck joints	Pre-1960	15	7	7	13	16
	Post-1960	13	7	10	11	13
Blocked drains	Pre-1960	12	3	3	6	11
	Post-1960	6	2	2	5	6
Handrails	Pre-1960	12	3	2	9	11
	Post-1960	5	3	2	4	5
Erosion	Pre-1960	5	1	0	5	5
	Post-1960	4	1	0	4	3
Services	Pre-1960	8	1	1	8	8
	Post-1960	6	3	3	6	4

* Respondents could tick none or more than one of these conditions, so each row of data does not total 23.

Figure 4.3 Distribution of durability problems with type of construction based on period of construction (pre-1960, post-1960).

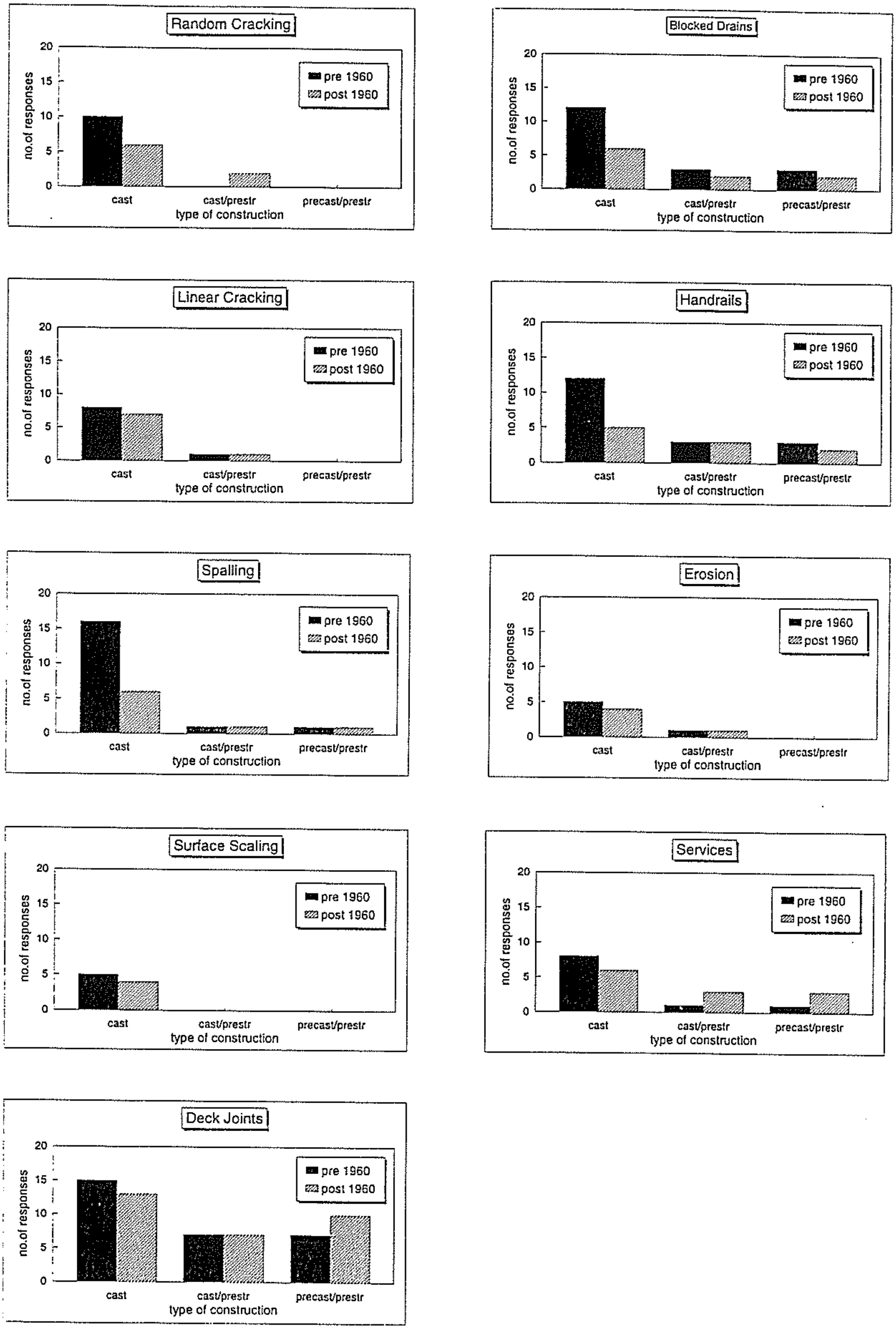
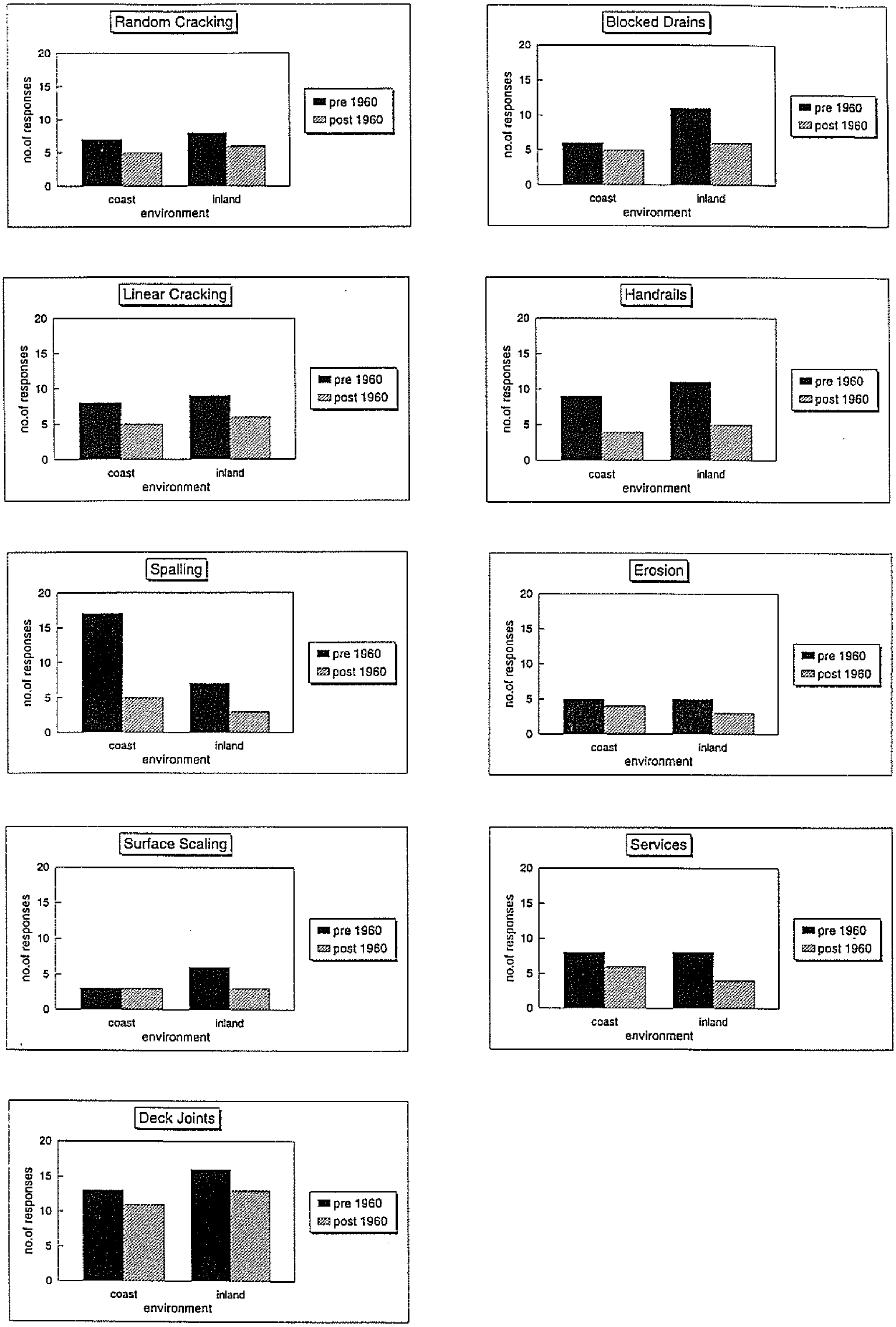


Figure 4.4 Distribution of durability problems with proximity to coast, based on period of construction (pre-1960, post-1960).



4.5 Frequency of Maintenance Tasks (Question 4)

Most respondents estimated that they carried out the nominated tasks between two times a year and once every two years. Handrail/guardrail and deck joint replacement tasks were carried out less frequently by some respondents. Graffiti removal was the least frequently performed task. Results are shown in Table 4.5.

Table 4.5 Frequency of performing maintenance tasks.

Task	Estimated frequency of performing task (number of respondents*)									
	On demand	**>3x year**	**3x year**	**2x year**	**1x year**	**1-2 yearly**	**2-6 yearly**	**6 yearly**	**>6 yearly**	**Seldom or never**
Clearing flood debris	11	1	-	3	7	3	2	0	0	1
Clearing deck channels	3	1	0	5	9	4	0	0	0	1
Cleaning deck drains	3	2	0	5	8	4	0	0	0	1
Repairs to hand/ guardrails	3	1	1	2	7	3	2	1	4	
Joint maintenance	4	0	2	3	5	4	3	0	4	1
Graffiti removal	5	1	1	1	3	2	3	0	0	9
Sign reinstatement	10	0	0	1	9	4	1	0	0	0

*Respondents could tick none or more than one of these conditions, so each row of data does not total 23.

4.6 Inspection Programmes (Questions 5 and 6)

Five of the seven respondents representing Transit New Zealand regions follow the Transit New Zealand requirements of two yearly regular inspections and six yearly detailed inspections. One of the remaining two reported four-yearly detailed inspections. The other reported two-yearly formal inspections by a bridge inspector and annual inspections by a consultant, with ongoing superficial inspections.

Of the 16 respondents representing local authorities, all but two reported programmed non-maintenance inspections at intervals between one and five years. Most were at one to two-year intervals, and one followed the Transit New Zealand requirements. The remaining two have just set up or are in the process of setting up inspection programmes.

All respondents reported that they used standard forms for reporting observations.

4.7 Storage of Data from Inspections (Question 7)

Five of the seven Transit New Zealand regions, and nine of the 16 local authorities who responded to the postal survey,record data from inspections using spreadsheets or databases. Some were in the process of changing systems. Systems currently used are:

BRIMMS (Bridge Maintenance Management System)	6
BAIMS[1] (Bridging Asset and Inspection Management System)	1
General spreadsheets and databases (Access/Paradox/Excel/unspecified)	7
RAMM (Road Assessment and Maintenance Management)	1
Bridge Spec (Opus International Consultants)	1

Reported uses of this data were for budgeting, programming and prioritising maintenance, record keeping, and presentation of data to client.

Nine respondents have been storing data manually to date (1998). Three of these have tried or have just started using electronic systems. One is currently reviewing suitable systems. Four thought such systems would be useful, two did not, and two were undecided. Points made by non-users were:

- Databases encourage programmed responses to problems rather than optimum solutions designed for individual situations.
- Manual systems are more accessible to non-computer literate inspectors.
- Manual systems are easier for the typical size of bridge stock managed by New Zealand local authorities (50-150).
- Electronic systems would improve management discipline, provide a diary capability, facilitate the transfer and feedback of information between the inspector and engineer, and provide a means for prioritising maintenance.
- On-site recording of observations might improve the standard of reporting but would serve little other purpose.

4.8 Maintenance Costs (Question 8)

Whether the costs quoted were for concrete bridges as requested, or for all bridges, is uncertain. Seven of the 18 respondents did not give an amount for all categories.

Totals for the 18 respondents who provided cost data were:

Routine inspections	$412,000
Routine maintenance	$3,143,000
Special investigation	$186,000
Major repair and rehabilitation	$2,060,000
Total	$5,801,000

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[1] BAIMS is a New Zealand developed database which was designed as a more user friendly version of BRIMMS. It is based on Access and data can be linked to the GIS system MapInfo.

Total costs, routine maintenance costs, and special investigation costs generally increase with the total number of bridges being administered, the exception being two local authorities with disproportionately low expenditure per bridge (see comments in following paragraphs). However, there is no relationship between any of the other costs and the total number of bridges. Nor is there any relationship between the cost and the number of bridges built before 1950 or in coastal exposure zones.

Routine inspection and maintenance account for over 70% of expenditure for 11 respondents. The other seven, which include four Transit New Zealand regions, spend 40-80% on major repairs. Special investigations constitute less than 15% of expenditure, even for those respondents spending a large proportion on major repairs.

Total expenditure per maintained bridge ranged from $200 to $3,500 for the local authorities, and from $1,400 to $4,900 for the Transit New Zealand regions. Transit New Zealand Northland, Auckland and Waikato regions and Auckland City have much higher expenditure, of $3,000-4,000 per bridge. Other Transit New Zealand regions ranged from $1,400 to $2,200 per bridge, and other local authorities ranged from $200 to $1,700 per bridge. The two local authorities with the most bridges (between 450 and 500) spent the least amount per bridge.

Typical inspection costs range from $30 to $230 per bridge, with no significant difference between Transit New Zealand regions and local authorities. Transit New Zealand Waikato region and Auckland City spend much more, around $450 per bridge. Typical routine maintenance costs range from $119 to $1,700 per bridge, with Transit New Zealand Auckland region and Auckland City again spending more, at $2,100-2,600 per bridge.

Transit New Zealand Northland, Auckland and Waikato regions together account for 61% of expenditure on major repair and rehabilitation.

4.9 Reinforcement Corrosion

4.9.1 Incidence (Questions 9 and 10)

One respondent did not answer question 9. Seven respondents estimated that over 20% of their bridges were affected by reinforcement corrosion. Only two of these have more than half their bridges in the coastal exposure zones. Of the fifteen who estimated that less than 20% of their bridges are affected, eleven have less than half their bridges in the coastal exposure zone. These data suggest that proximity to the coast is not the only factor in determining corrosion risk. Age is likely to be the second factor (Section 4.3.2), but the data from this question cannot be analysed to confirm this because the ages of many local authority bridges are unknown.

Spalling of cover concrete, exposed bars, cracking parallel to reinforcement, and rust stains were the symptoms most commonly associated with corrosion. Other symptoms quoted were drummy concrete, wet lines on soffits, efflorescence, water leakage, discolouring, previous repairs, voids and porous concrete.

4.9.2 Treatment (Questions 11-14)

Over half the respondents said they would initiate further investigation if reinforcement corrosion was discovered, although often the need would be assessed case by case. Two referred to investigations to check structural integrity. Eight referred to the need to establish the cause of the damage.

Both epoxy mortars and proprietary cementitious repair materials had been used by most respondents. Site-mixed cementitious materials were used by half the respondents.

The most common reason for choosing epoxy mortars was convenience (14 respondents). Eight quoted their durability, and six the cost and familiarity with the material. Two commented that epoxies were useful for repairing small areas.

The most common reason for choosing proprietary cementitious materials was their durability (13 respondents). Their cost and convenience were identified by six respondents. Only two chose them on the basis of familiarity. Other advantages identified were suppliers' backup, training of licensed applicators, the elimination of mixing problems, good specifications for application provided, and the convenience of repair kits. One thought they were better for larger spalled areas.

Site-mixed cementitious materials had the advantages of cost and convenience (six respondents each), and familiarity (five respondents).

Epoxy mortars and proprietary cementitious materials were both rated as successful by 14 respondents. Three regarded the epoxies as unsuccessful, and several commented that epoxy mortars tended to disbond. None reported that proprietary cementitious materials were unsuccessful although three commented that correct diagnosis, good preparation and good quality assurance were needed when they were used. Site-mixed cementitious materials were considered successful by seven respondents and unsuccessful by three respondents. Three commented that workmanship was important in achieving a successful repair with site mixed mortars.

4.9.3 Electrochemical Repair Techniques (Questions 15 and 16)

Sixteen respondents were familiar with the concepts of cathodic protection, and 11 were familiar with realkalisation and desalination. Seven had considered using electrochemical techniques, with the permanent solutions they offer being the main advantage. Thirteen had not considered using them, and reasons quoted were the cost and no suitable applications, such as large scale repairs. Two respondents acknowledged that the decision whether to treat or replace a bridge depends on traffic capacity and road alignment and other problems rather than on its condition or load capacity. Therefore, these factors need to be taken into account as well as the cost-benefit analysis of different repair options.

4.10 Other Comments (Question 17)

The following are direct or abbreviated quotes from respondents. They were selected for their general applicability.

"Most common problem is lack of cover to reinforcement. Carbonation is found in older bridges (built in 1930s) but not a serious problem. Chloride ion contamination affects only a few structures which are permanently exposed to salt water. Lack of cover is main cause of corrosion."

"Maintenance tends to be preventive rather than repair."

"Concrete bridges last at least 50 years with little repair if concrete is well compacted and good cover provided. The two bridges with major repairs needed are in a coastal environment. One was built in the 1930s and chloride contamination had reached the reinforcement. The other was built in the 1960s and cover was insufficient. One further bridge over 70 years old may be repaired in the future, and it is suspected that the concrete is carbonated through to the steel. On the basis of this experience, we expect concrete in new bridges built to current requirements will be maintenance-free for well in excess of 50 years."

"Cracks are wider in older bridges, and are finer in newer bridges, due to changes in reinforcing practice."

"Graveyard style handrails are a problem."

"Epoxy injection is successful for non-active cracks."

"It is often poor detailing which is a major contribution to problems with concrete bridges, i.e. joints, drainage ports, bearings. Joint failure can lead to damage to deck edges and water access to bearings which can cause them to seize. Drainage ports which block easily mean that water cannot run off and can contribute to reinforcement corrosion. Bearing failure is reasonably frequent in older sliding steel/steel bearings, which tend to seize up and cause spalling of the bearing supports."

"From our observations precast prestressed elements, double hollow core, U-beams, I-beams, etc. show no or very very low sign of deterioration. Reason: higher quality control on reinforcement, strand placement, steam curing, high strength concretes used."

"Older precast systems - log beams tend to display (1960s) corrosion problems with stirrups and low cover to strand. High problems around boxout areas left for drainage scuppers vertically down through deck."

"Deterioration in newer structures usually result of poor workmanship - usually lack of cover, occasionally poor compaction. Cracking observed typically fine and controlled by adequate reinforcing percentage."

"Older cast-in situ structures appear to suffer from poor workmanship and poor concrete/inconsistent quality. Lack of cover is a major problem with older structures. Inadequate deck steel tends to lead to uniform and widespread deck cracking."

5. DISCUSSION

The aim of this project was to analyse existing information on the age, location, condition and maintenance of concrete road bridges to identify means by which the durability of existing and future structures could be improved. The two aspects to the research were to:

- assess the effectiveness of management of the bridge stock;
- identify concrete durability problems.

These have been considered separately in the following discussion, although some issues are common to each.

5.1 Management

5.1.1 Information on Bridge Stock

The more that is known about the bridge stock the better it can be managed. This includes descriptions of the location, function, design, construction, condition and maintenance history of each bridge.

Information on the age, location and structure of all state highway bridges is stored on the *Bridge Descriptive Inventory* maintained by Transit New Zealand. Not all entries are complete and problems with keeping some aspects up-to-date are recognised (van Barneveld 1994). For example, changes in road alignment and reference positions have resulted in inconsistencies between recorded, actual and signposted route positions. However, the mechanism is in place for an accurate description of all bridges and culverts to be available. Of the 2,277 concrete road bridges identified on the inventory, only 4% were of unknown age. This indicates that the records of basic data are fairly complete.

In contrast, the local authorities each have their own inventories. Of the 19 local authorities who responded to the initial approach for information, four were unable to supply data on the age distribution of their bridges, and only two knew the ages of all their bridges. Six had 20-50% of their bridges listed as "age unknown". Some descriptive data on bridges have been mislaid during local body amalgamation.

Neither Transit New Zealand regions nor local authorities have a consistent method of recording data on the condition of their bridges or on the amounts spent in maintenance. One local authority noted that its consultant had reported only one case of concrete deterioration. It is unlikely that only one bridge should show any sign of deterioration in this particular area, and so the information may not have been managed adequately. Wood (1994) found that most bridging authorities see the need for a bridge management system, and this was supported by the responses obtained for the current research.

A nationwide bridge management system would have several benefits. First, because Transit New Zealand regions and local authorities typically administer between 50 and 300 bridges each, it is not economical for each to develop its own system for bridge management. Second, jurisdictions over roads change as do boundaries between authorities. When a bridge changes hands, the information about it needs to be able to be transferred easily to the new managing authority. Third, Transit New Zealand and local authorities often contract consultants to manage their bridge stock and the information needs to be able to be transferred with such contracts. One respondent stated that his answers were based on inspections carried out in the first year of a three-year contract, implying that those records of previous inspections were not available to him.

Wood (1994) recommended that all bridge maintenance functions should operate under a unified software system. For example, the Road Directorate of the Danish Ministry of Transport has developed a system for managing their 2,000 structures. This system is used to record administrative and technical data (like the *Bridge Descriptive Inventory*), information on the present maintenance conditions of the bridges, and economic data such as allocations and budgets for various repair solutions. More powerful and user-friendly systems are likely to be available now. The key to the success of any such system is that it must make it easy to systematically record, collate and manipulate data.

Development of an appropriate asset management plan for Transit New Zealand is part of the current National Bridge Consultant's contract[2]. To achieve the ideal of a consistent approach to asset management between Transit New Zealand and local authorities, the National Bridge Consultant's recommendations need to be disseminated to local authorities.

5.1.2 Inspection and Maintenance

The need for local authorities to have asset management plans is probably partly responsible for the universal use of formal inspection programmes among survey respondents. Inspections are generally carried out at the frequency recommended by Transit New Zealand, or more frequently. Some knowledge of the details covered by each inspection is needed to ascertain whether these programmes are providing appropriate information.

As discussed in the previous section, a universal inspection and reporting system with electronic storage of data would help to provide consistent information on all bridges throughout the country. This would make it easier to assess regional differences than by comparing subjective observations as was done in this project. Appropriate funding levels would in turn be easier to determine, as acknowledged by van Barneveld (1994).

Few respondents "didn't know" whether the specified defects affected their bridges. The defect about which the largest number of respondents were unaware was scaling. Whether this reflects a lack of awareness of its significance or a lack of recognition of the symptom is not known.

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[2] Transit New Zealand Head Office Contract 8/97-008 for National Bridge Consultant, and currently held by Opus International Consultants, Wellington.

Responses to the survey questions about reinforcement corrosion indicated a reasonable understanding of how to identify the problem.

Many of the respondents appreciated the need to investigate instances of corrosion, although, in retrospect, question 11 was ambiguous and did not invite the respondents to describe the nature of the investigations carried out.

A surprising number of respondents were still using epoxy patch repairs, which are now generally recognised to be less durable than cementitious repair systems.

The survey may have under-estimated the number of respondents aware of electrochemical repair techniques because, as one of them noted, "familiarity" involves a greater understanding than "awareness". Therefore most are likely to be aware of cathodic protection but fewer, perhaps half, have heard of desalination and realkalisation. More Transit New Zealand agents than local authorities were familiar with desalination and realkalisation. This is probably because the licensees have targeted Transit New Zealand consultants in its marketing.

Overall, no major shortcomings in understanding were apparent among those responsible for inspection and maintenance. However, updated information on repair techniques for concrete damaged by reinforcement corrosion is needed.

5.2 Concrete Durability and Repair Technology

Most respondents reported that fewer than 40% of bridges were affected by maintenance and durability problems. The exception is problems associated with deck joints, which affect a much higher proportion of respondents' bridges. Maintenance and durability problems are more common in bridges built before 1960.

The survey findings on maintenance and repair costs suggest that the routine maintenance tasks listed in Table 4.4 (Section 4.4 of this report) account for most of the expenditure, with major repairs to deteriorating concrete being less significant in most areas. These maintenance tasks are, by their nature, ongoing and are unlikely to increase with time.

In contrast, as the bridge stock ages, expenditure related to concrete durability could increase. Based on the data provided by Transit New Zealand and local authorities, about 23% of concrete bridges were built more than 50 years ago and about 67% have been built since then. Durability problems can be expected to increase as the older group ages.

Some means of predicting future problems is desirable so that cost-effective preventive action can be taken or replacement plans made before the problems become severe. For example, if a bridge is still functioning satisfactorily in all other respects, the onset of carbonation-induced reinforcement corrosion could be delayed by applying a protective coating before the carbonation depth reaches the reinforcement.

The data in Figures 3.2 and 3.6 show that many bridges were built between 1950 and 1970. Although site investigations carried out for Transit New Zealand regions and local authorities by Opus International Consultants (Opus), Central Laboratories, show that most bridges needing major repairs because of deteriorating concrete are over 50 years old, general improvements in construction and design practices mean that repair costs will not necessarily rise in proportion to bridge age.

A particular improvement has been the widespread use of precast components for bridge superstructures, which means that most concrete is cast and cured in factory conditions. Another improvement is the introduction of formal quality assurance procedures for all stages of design and construction, which should overcome shortcomings in the chain of responsibility and supervision.

Nevertheless, certain design and construction practices might cause durability problems in bridges of specific age groups. For example, in the 1960s precasters often used calcium chloride as an accelerator, but although this has caused problems on building panels no evidence of similar problems has been seen on bridges. Detailing of 1960s precast construction sometimes introduced factors such as low cover to metallic components, which increases the potential for corrosion.

Whether the apparently low incidence of scaling is real or whether it reflects a lack of recognition is not known. Most scaling observed by Opus Central Laboratories has been minor, and therefore unlikely to attract attention from a maintenance aspect. Scaling can be caused by freeze-thaw cycles. The extent and severity of scaling in areas subject to freezing temperatures should be examined. If severe and associated with cracking, as freeze-thaw attack often is, there is an increased risk of reinforcement corrosion. This deterioration is likely to accelerate because the cracking and scaling continuously expose fresh concrete surfaces. Scaling caused by the effects of chemicals is more likely to occur as isolated events unrelated to bridge age or location, e.g. exposure to unusual groundwater conditions, chemical spills, or problems with the chemistry of the cement used in the component.

Problems with deck joints and drains, and handrails/guardrails were common in bridges of all ages and this is reflected in maintenance costs as discussed earlier in this Section 5.2. These problems should be addressed at the design stage. From a survey of bridge controlling authorities, Nicholas (1987) reported 28% of expansion joints, 9% of concrete handrails and guardrails, and 5% of deck drainage systems on bridges would need repairs within 12 months of that survey. A conclusion also reached in his research is that there is a clear need to develop a low maintenance method for accommodating movements in the superstructure.

Cracking likely to be caused by drying shrinkage appeared to affect more North Island regions than South Island regions. The rounded alluvial aggregates used in bridge construction in parts of the South Island need less cement to achieve a given strength than do crushed aggregates. Consequently concretes made with these rounded aggregates shrink less on drying than those containing crushed aggregates.

5.3 Reinforcement Corrosion

Reinforcement corrosion is the biggest threat to concrete durability of bridges on New Zealand roads and is the subject of the remainder of this discussion.

Work by Rowe & Freitag (1984) suggested that 20% of bridges need remedial work because of reinforcement corrosion and that many more have less severe damage. Although postal survey questions 2 and 9 do not distinguish between "no bridges affected" and "nearly 20% bridges affected", the data from question 9 suggest that overall 10% to 30% of the respondents' bridges are affected. This is in reasonable agreement with the earlier work, considering the subjective nature of the survey responses compared to the systematic methods of the earlier work, and the degree of damage that could be interpreted as "affecting" the bridges.

Although analysis of the responses to questions 2, 3 and 9 reveals some inconsistencies, overall the incidence of corrosion apparently increases with bridge age and exposure to contamination with chlorides from seawater or sea spray. Thus authorities having bridges at the most risk are those with a high proportion of older bridges and bridges in the coastal exposure zones, for example Transit New Zealand Northland and Taranaki districts, each with over half their bridges more than 50 years old and over 90% in the coastal exposure zones.

Transit New Zealand Northland district estimated that less than 20% of their bridges in either age group were affected by spalling. This estimate could be a result of the subjective nature of the survey. It could also reflect the fact that the coastal exposure zones defined by NZS 3101:1995 give only broad indications of corrosion risk, and that the micro-climate affecting any particular site could differ from that indicated by the zone, as shown by the following examples.

Nearly 50% of Christchurch City's bridges are older than 50 years and nearly 70% are in the coastal zones. Two districts with more than 90% of their bridges in coastal exposure zones, Thames-Coromandel and South Taranaki, provided no data on the age distribution of the bridges. However, in these three areas, more than 20% of the bridges in both age groups were reported to be affected by spalling.

Auckland City and Westland District also have more than 90% of their bridges in coastal exposure zones but fewer than 25% are more than 50 years old. In Auckland City less than 20% of post-1960 bridges were believed to be affected by spalling. In Westland over 20% of bridges in both age groups were believed to be affected.

Ruapehu district has no bridges in the coastal zone and most bridges of known age were built after 1950 (24% are of unknown age). Less than 20% of its post-1960 bridges and more than 20% of its pre-1960 bridges were reported to be affected.

As some respondents noted, each case of reinforcement corrosion needs to be assessed individually. Thus it might be more economical to delay investigating minor cases and concentrate on those where damage is extensive or severe.

However, repair should not be left until structural integrity is threatened. Rather, the investigation should concentrate on identifying the cause of the corrosion so that a repair, both to reinstate spalled concrete and to prevent further deterioration, can be carried out before a significant cross-section of the reinforcement is lost.

Epoxy patch repairs are still widely used, largely for their convenience and especially for small repairs. However, they do not offer a permanent solution. Steel encased in epoxy will not corrode, but the corrosion will develop on steel adjacent to the patch because of the different electrochemical environments provided by concrete and epoxy. Epoxy patches have different thermal and moisture movement characteristics to concrete and this sets up stresses at the interface which often cause the patch to disbond. This was observed by several respondents. Nevertheless, epoxy patches may be appropriate for temporary repairs while the long-term future of the bridge is evaluated.

Proprietary cementitious repair materials are more compatible with concrete, making them more durable, and this was recognised by just over half the respondents. They also overcome the problems of site-mixed concrete by eliminating mixing problems. Some manufacturers further reduce the risk of workmanship error by providing detailed specifications and/or licensed applicators, and this was appreciated by some respondents.

Nicholas (1987) found that a higher proportion of cement mortar repairs were defective than epoxy mortars. Cementitious repair technology has advanced significantly since the mid-1980s and the relationship might now be reversed.

Cathodic protection is currently acknowledged as a repair option in the *Bridge Inspection and Maintenance Manual* (Transit New Zealand 1991), but desalination and realkalisation also need to be included when the manual is next updated. About 10 privately owned concrete structures in New Zealand have been cathodically protected and realkalisation is being considered for another three. Although many bridge authorities are aware of the electrochemical treatments, there have been no applications on New Zealand bridges by 1998. Many respondents suggested that the treatments are too expensive.

The electrochemical treatments address the cause of corrosion, unlike patch repairs which simply replace concrete in the damaged area. They thereby prevent continued corrosion and therefore the need for future repair. Thus although the initial cost might be higher than patch repair, the long-term benefits of these treatments need to be considered when selecting repair techniques.

Another obstacle to the acceptance of the electrochemical techniques is the lack of local evidence of performance. This is a "chicken and egg" problem. Further, it is not practical to install a trial system and then wait ten years to monitor cost-effectiveness before adopting the technology. A survey of the effectiveness of overseas applications would be the best way to assess if they are viable. This should be carried out by an organisation that is independent of the developers and licensees of proprietary systems.

How does the durability of concrete in existing bridges relate to the 100-year design lives now being specified for bridges, when NZS 3101 gives specifications for a 50-year design life? The survey responses suggest that, while most bridges affected by reinforcement corrosion are older than 50 years, most bridges more than 50 years old are not seriously affected. Site inspections indicate that corrosion becomes a major problem only when the depth of concrete cover is significantly less than the requirements of today's standards, or when the cover concrete is highly permeable because of poor consolidation or mix design or perhaps lack of curing. The risk is increased for bridges near the coast because of the possibility of contamination by salt. Evidence to date therefore suggests that the current specifications of NZS 3101 are certainly sufficient to provide more than 50 maintenance-free years, provided good design and construction practices are adopted.

The Transit New Zealand Bridge Manual states "the design life of a bridge is assumed to be 100 years in normal circumstances". This requirement is at odds with the 50-year design life specified in NZS 3101 in that a bridge designed in accordance with the durability requirement of the standard will not necessarily reach a 100-year design life. Based on international bridge design codes, a revision of Table 5.5 in NZS 3101 has been proposed to provide interim guidance to designers on the durability requirements to achieve a 100-year design life. A copy of this proposal is included in Appendix 3.

As more advanced concrete technologies are introduced to improve the durability of concrete structures, it becomes more important to ensure that design and site practices do not become the weak link. An important aspect of concrete durability is therefore proper training of construction personnel. The Cement and Concrete Industry Training Board is currently working on training programmes with the Building and Construction Industry Training Organisation to address the issue of training.

6. CONCLUSIONS

The following conclusions were based on responses from Transit New Zealand regional offices and selected local authorities, and may not apply to the total bridge stock.

- Transit New Zealand's *Bridge Descriptive Inventory* contains detailed descriptions of most of New Zealand's state highway bridges. Local authority records are generally less complete. Bridges of unknown age comprise 4% of the state highway stock and 17% of those administered by the 15 local authorities who could provide information on age distribution.

- Concrete state highway bridges that are more than 50 years old comprise 32%, compared to 14% of bridges administered by the 15 local authorities who provided information on age distribution. Bridges built since 1970 make up 21% of state highway bridges and 30% of the local authority bridges.

- All the bridge controlling authorities who were surveyed had formal inspection programmes which should help early identification of problems.

- A well maintained, user-friendly, universal management system would improve consistency of data recorded by the different bridge controlling authorities, and could therefore help to establish appropriate maintenance funding levels.

- Personnel responsible for bridge management have a reasonable understanding of durability issues, but need more current information on treatments used for reinforcement corrosion.

- Maintenance and durability problems affect up to 40% of bridges, and are more common on older bridges.

- Deck joint deterioration is the most common maintenance problem on concrete bridges. Bridges of all ages are affected.

- Surface scaling, indicative of frost or chemical attack, was not well recognised or recorded in some regions/districts where it might be expected, so no comment can be made on the incidence of these types of deterioration.

- Linear cracking, usually caused by shrinkage, is more common in the North Island. This might be related to the types of aggregate used.

- Reinforcement corrosion is potentially the most threatening concrete durability problem although routine maintenance and inspection of bridges currently accounts for the bulk of the bridging repair and maintenance bill.

- Reinforcement corrosion is more common in older bridges and is usually related to design or construction defects. Improvements in design and construction in the last 50 years, particularly with the introduction of modern precast practice, mean that the risk will not necessarily increase as the bridge stock ages.

  Current New Zealand standard specifications for concrete construction, if adhered to, ensure a maintenance-free life of at least 50 years. Thus construction industry training programmes are important to ensure the durability of bridges to be built in the future.

- Reinforcement corrosion is more common in bridges exposed to salt contamination from seawater.

- Epoxy repair materials are widely used to repair spalled concrete although the repairs often disbond. Repair materials are often selected on the basis of familiarity and convenience.

  Cost is also important and has been a prohibiting factor in the introduction of electrochemical treatments. Although initially more expensive, the long-term durability offered by electrochemical repair techniques should be considered when repair materials are selected.

7. RECOMMENDATIONS

- Design and Construction Issues
    - Ensure that current specifications for concrete construction are adhered to in bridge design and construction.

- General Management of Bridge Stock
    - The improvement recommendations, which are anticipated to arise from the National Bridge Contract, should be promptly implemented to maximise potential benefits for all bridge controlling authorities.

    - The National Bridge Consultant's advice should be disseminated to local authorities to assist the development of bridge management plans.

- Long-Term Durability Issues
    - Long-term durability should be considered when selecting repair systems for concrete damaged by reinforcement corrosion.

    - An independent evaluation of the effectiveness of electrochemical repair systems installed overseas should be carried out.

    - The performance of methods currently used to accommodate bridge superstructure movements (e.g. deck joints) should be investigated so that shortcomings in their effectiveness and durability can be overcome in future bridge construction.

    - The incidence of scaling damage on bridges that are likely to be affected by freeze-thaw effects should be further investigated.

- Reference Documentation
    - The *Bridge Inspection and Maintenance Manual* should be revised to include information on desalination and realkalisation, and on proprietary cementitious repair materials.

- Future Directions
    - Methods of predicting future deterioration in concrete bridges should be investigated so that cost-effective preventive action can be taken before significant damage develops.

    - A proactive approach to bridge maintenance issues, whereby remedial work can be carried out on bridges more than 50 years old, should be developed to reduce future maintenance costs and add to the life expectancy of the structure.

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APPENDIX 1

DURABILITY OF NEW ZEALAND CONCRETE BRIDGES

Position paper (by Bruce & McGuire 1996)
for AUSTROADS project T&E.B.41, 3B.4.1
Concrete structures - durability, inspection & maintenance procedures

DURABILITY OF NEW ZEALAND CONCRETE BRIDGES

S.M. Bruce*, J.F. McGuire**

May 1996

1. INTRODUCTION

This paper has been prepared as a contribution to Austroads Project 3B41 "Concrete Structures - Durability, Inspection and Maintenance Procedures". The following paper provides a summary of the nature of New Zealand's state highway bridge stock, deterioration mechanisms which affect the concrete bridges, the inspection techniques used, and remedial measures taken. It also describes the codes and standards used to ensure construction of durable concrete, and research currently underway in New Zealand related to concrete durability.

This paper specifically addresses the durability of reinforced concrete in bridges, and the mechanisms likely to cause deterioration of the concrete itself or initiate corrosion of the reinforcing steel. Deterioration due to overloading, pier scour, seismic activity or other events likely to cause structural failure is not considered.

2. NEW ZEALAND'S BRIDGE ASSET

Transit New Zealand is responsible for management of New Zealand's state highway network; including the bridges and major culverts. Management of other public roads and bridges is vested in the appropriate local authority, although Transit New Zealand contributes some funding to their maintenance. A summary of the number and type of bridges and major culverts on the New Zealand state highway network is shown in Tables 1 to 3. Figure 1 shows the age distribution of state highway bridge structures.

Transit New Zealand contracts out all design, construction and maintenance services on a competitive pricing policy (CPP) basis.

3. CONCRETE DETERIORATION MECHANISMS

3.1 Reinforcement Corrosion

Chloride contamination and carbonation are the major contributing causes to reinforcement corrosion.

(a) Chloride Contamination

Reinforcement corrosion as a result of chloride contamination is the most significant durability problem affecting New Zealand's concrete bridges. Chlorides are usually an external contaminant derived from the sea. Many New Zealand bridges cross saline coastal estuaries, are sited within the coastal margin, or are influenced by salt carried inland by onshore winds.

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* Works Consultancy Services Ltd

** Transit New Zealand

Table 1: State Highway Bridges and Culverts

Type	Number
Bridges	2392
Bridges with concrete superstructures	1820
Bailey bridges	2
Major culverts (waterway area greater than 2.5 m^2)	1192

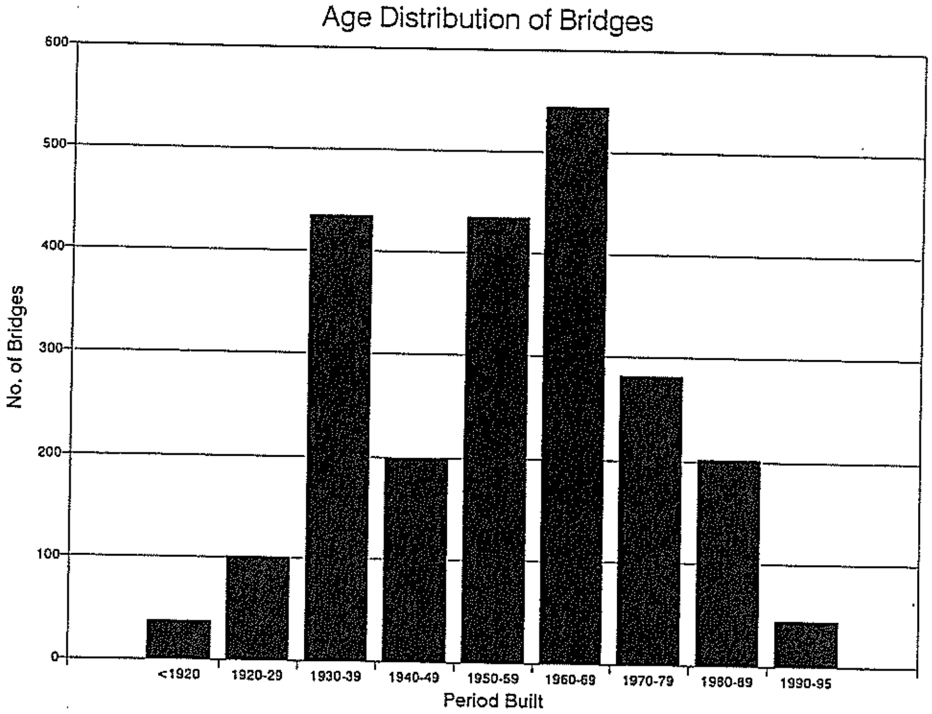
Table 2: Superstructure Materials on State Highway Bridges

Superstructure Material	% of Bridges
Steel	20
Concrete cast in situ reinforced	47
Concrete cast in situ prestressed	3
Concrete precast reinforced	1
Concrete precast pretensioned	24
Concrete precast pre/post-tensioned	2
Masonry	2
Other	1

Table 3: Construction Materials in Major Culverts on State Highways

Culvert Material	% of Culverts
Concrete cast in situ reinforced	59
Concrete precast reinforced	21
Steel	17
Timber	1
Other	2

Figure 1: Age Distribution of New Zealand State Highway Bridges



Local exposure to chloride contamination depends on both proximity to the coast and the strength and direction of the prevailing wind, and these factors are recognised in NZS 3101 : 1995 "Concrete Structures Standard". The exposure classification maps derived from this standard for the North and South Islands of New Zealand are shown in Figure 2.

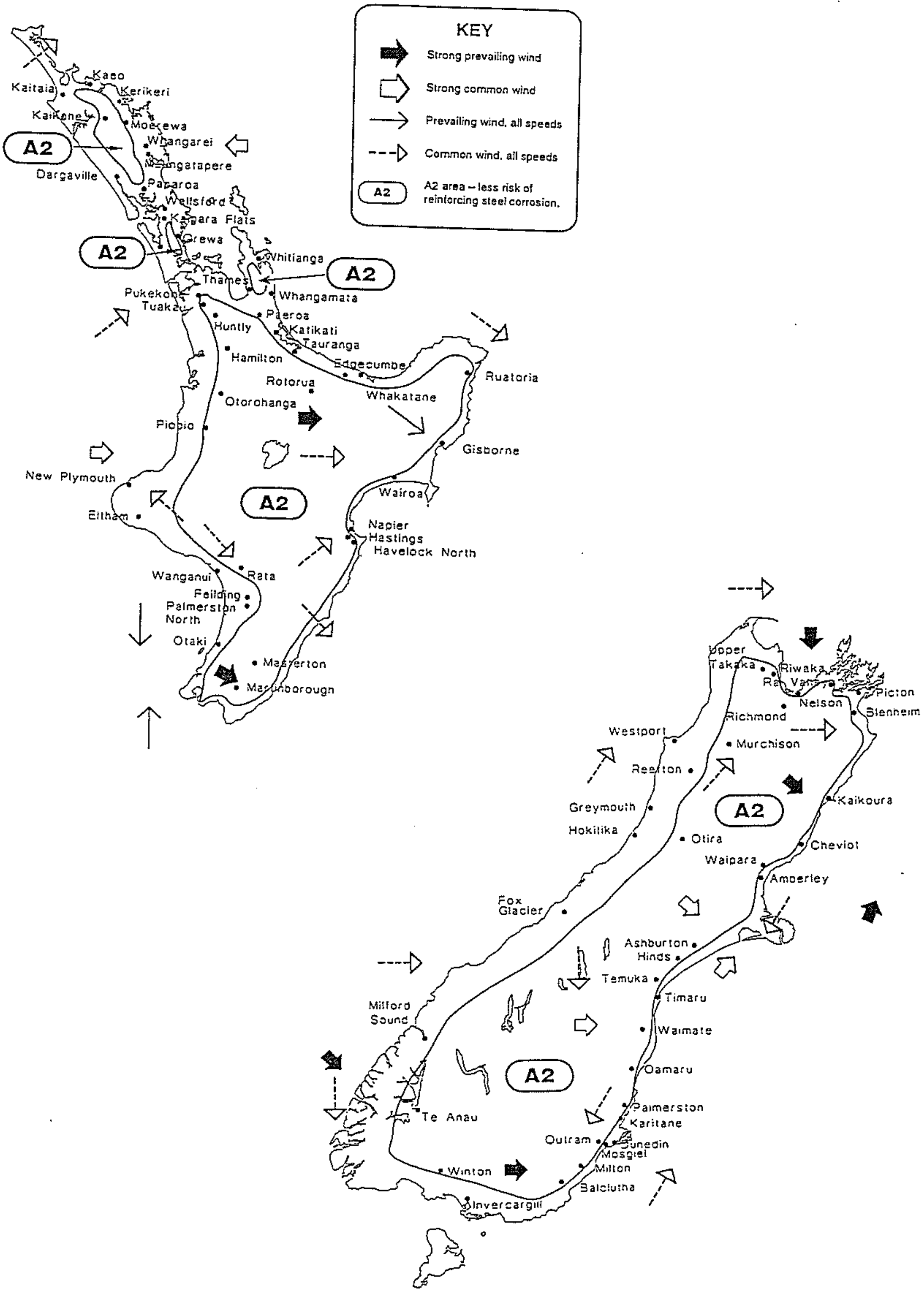
Chlorides can also be included in fresh concrete either in the form of contaminated aggregates or accelerating admixtures. It is likely that some bridges constructed before about 1940 contained aggregates from locally won unwashed beach deposits which may have contributed to chloride contamination. Chloride-containing accelerating admixtures were used in limited quantities in the New Zealand concrete industry from the late 1950s through to the early 1970s, although no associated bridge durability problems have yet been encountered.

Deicing salts are not currently used on New Zealand roads. However, a proposal to salt the Desert Road in the central North Island, to reduce winter road closures, is currently being considered. The impact of deicing salts on concrete bridges in the northern hemisphere has been well documented. Bridges on the Desert Road will be carefully monitored if salting is approved.

(b) Carbonation

Reinforcement corrosion as a result of carbonation is a less significant problem than chloride induced corrosion. This deterioration commonly affects inland bridges or sheltered bridge sub-structures where climatic conditions are more suited to carbonation. In these conditions the corrosion rates, hence the rates of deterioration, are relatively slow.

Figure 2: Exposure Classification Maps for the North and South Islands of New Zealand (taken from NZS 3101 : Part 1 : 1995)



3.2 Alkali Aggregate Reactivity (AAR)

AAR occurs in about 10% of structures in areas where potentially reactive aggregates are used. Volcanic aggregates sourced from both Taranaki and the Central Volcanic Region have been identified as reactive. Abutments are most often affected. In most cases the effects are believed to be cosmetic only. Four bridges to date have required major repair due to deterioration of the superstructure caused by a combination of factors, including AAR, and another four with extensive abutment cracks have been identified.

3.3 Sulphates

Sulphate attack is currently not a major issue for concrete durability in bridges. However, the risk is higher in the central North Island geothermal areas where bridge foundation concrete can be exposed to "aggressive" soils containing sulphate ions.

3.4 Freeze-Thaw

Freeze-thaw damage is a minor problem for concrete durability in New Zealand. Repetitive freezing and thawing cycles which would promote this deterioration are only likely to occur in Otago and inland Canterbury, including the roads crossing the Southern Alps, and in the central North Island. Deterioration in the latter area is confined to superficial cracking of kerbs and wingwalls, and is believed to be associated with AAR.

3.5 Physical Damage

Physical damage due to vehicle impact occurs irregularly. It includes collisions with overpass structures with restricted height clearance, and damage to the concrete handrails and end posts which predominate on pre-1960s bridges.

4. INSPECTION AND INVESTIGATION TECHNIQUES

Routine bridge inspections are carried out under the guidelines of the Bridge Inspection and Maintenance Manual (Transit New Zealand, 1991a). The frequency for bridge inspections is set out in the Bridge Inspection Policy (Transit New Zealand, 1991b) which identifies the following levels of inspection:

- Superficial Inspection

This inspection should identify any obvious defect which may affect the safety of highway users or anything else needing urgent attention. The minimum frequency for inspection is set out in the Maintenance Guidelines for State Highways (Transit New Zealand, 1991c).

- General Inspection

The procedure required is described in the Bridge Inspection Guide (Department of Transport, 1983) and should be carried out at intervals not exceeding two years.

- Detailed Inspection

The procedure described in the Bridge Inspection Guide (Department of Transport, 1983) should be followed but all external surfaces above water level and, where appropriate, all internal surfaces should be inspected at close quarters. These inspections should be carried out at intervals not exceeding six years.

The inspections are carried out by Transit New Zealand's regional maintenance consultants.

If, in the course of a general or detailed inspection, faults are identified which are outside the competence of the normal inspection staff then specialist consultants are permitted to be employed.

There are several consultants in New Zealand who specialise in concrete durability problems and who conduct on-site condition surveys. Commonly the problem identified is corrosion of reinforcing steel. The following techniques are used, in conjunction with an appropriate sampling frequency, to give an indication of the current and future risk for corrosion:

- detailed visual inspection (including identification of cracks and delamination)
- reinforcement cover depth
- chloride content of concrete
- carbonation depth.

Additional properties which may be measured in specific situations include:

- half cell potential of reinforcement
- resistivity of concrete
- initial surface absorption (ISAT)
- concrete compressive strength and density
- tensile strength of steel from hardness determinations
- cement content of concrete
- water/cement ratio of concrete
- sulphate content of concrete.

5. REMEDIAL TECHNIQUES

Remedial options available to overcome the current and ongoing deterioration associated with reinforcement corrosion include:

5.1 Patch Repair Systems

Proprietary cementitious repair systems are the most commonly used remedial technique for major repairs of New Zealand concrete bridges. These systems include trowellable patching mortars as well as free flowing shrinkage compensated micro-concretes, and are entirely prepackaged apart from the mixing water. Repairs are carried out by specialist contractors approved by the material manufacturer. The variable quality of repair materials batched on site is considered to be unacceptable, and consequently they are not recommended.

Cementitious repair systems have been used for repair of a number of state highway bridges in the past five years. The cause of damage in these bridges was both chloride and carbonation induced reinforcement corrosion. Repairs are carried out on chloride contaminated structures with the understanding that future maintenance may be required to reinstate areas of continuing deterioration.

5.2 Coatings

Coatings are an integral part of many cementitious repair systems, particularly in coastal locations where ongoing chloride contamination is likely. They are commonly applied as the final stage of a major repair contract.

Coating systems used to date consist of impregnation with a silane-siloxane to block liquid water and chloride ions, followed by a solvent- or water-based acrylic coating which is often pigmented.

Coating systems should be considered in future as a preventative maintenance technique to prevent deterioration of relatively new concrete structures where the risk of chloride contamination is high.

5.3 Cathodic Protection (CP)

Impressed current cathodic protection systems have been available in New Zealand since 1987. To date, their installation has been restricted to wharves, multi-storey commercial premises and apartment buildings. There have been no installations on state highway bridges. Cathodic protection is considered as an appropriate remedial option where chloride contamination is high.

With the continuing development and refinement of different anode systems, CP systems are becoming more cost competitive relative to conventional repair techniques, especially once the long term benefits of CP installation are accounted for.

5.4 Chloride Extraction/Realkalisation

In April 1996 proprietary chloride extraction and realkalisation processes were launched in New Zealand as a remedial technique for concrete structures affected by reinforcement corrosion. To date, the techniques have not been used on state highway bridges. Chloride extraction will potentially be the most useful technique.

5.5 Replacement

The deterioration of a reinforced concrete bridge due to reinforcement corrosion or other concrete durability factors can contribute to the decision to replace a bridge, but is unlikely to be the sole reason. Transit New Zealand uses a cost/benefit analysis to determine whether a bridge needs replacing. The analysis considers factors such as regional strategic decisions, bridge age and condition, structural/seismic factors, bridge alignment and traffic volumes.

6. CONSTRUCTION STANDARDS

The criteria for design of new concrete bridges is set out in the Bridge Manual (Transit New Zealand, 1991d). The Bridge Manual calls up NZS 3101 : Part 1 : 1995 for design of concrete for durability, which considers design in terms of the compressive strength of concrete and cover depths required for given exposure conditions (see Figure 2).

An anomaly exists between the 100 year design life requirements of the Bridge Manual and the 50 year specified intended life quoted in NZS 3101 for durability purposes. The provisions in NZS 3101 require modification to provide criteria for design for a specified intended life of 100 years, and to allow for the use of alternative cement types and blends. A research proposal for this work is currently under consideration (see Section 8).

Curing is specified in NZS 3101 according to exposure classification. For members subject to inland exposure conditions, the concrete is required to be wet cured for three days under ambient conditions. For coastal and tidal exposure conditions, the members must be wet cured for seven days at ambient conditions.

Requirements for good construction practice, including adequate fixing of reinforcement and the placing, compacting and curing of concrete, are described in NZS 3109 : 1987.

The use of precast prestressed concrete beams and deck sections in recently constructed bridges has markedly improved the concrete quality, and should improve the long term durability of these elements.

7. TEST METHODS FOR DURABILITY RELATED CONCRETE ACCEPTANCE

Concrete acceptance is traditionally based around compressive strength tests using cylinders. In recent major works (e.g. Museum of New Zealand, Sky Tower), durability-related testing has been specified in the form of the rapid chloride test (AASHTO T277, 1993). In addition, shrinkage testing (AS 1012.3 : 1992) has been specified to prove the concrete in question meets a maximum prescribed shrinkage level to minimise cracking, and on the Sky Tower site a water permeability test has been specified.

8. RESEARCH

Transit New Zealand fund a significant volume of roading related research. The total value of funding in 1995/96 was $1.8 million. No concrete durability projects are currently being funded. Proposals currently under consideration for 1996/97 include:

- preparation of modified criteria for durability design (NZS 3101 : 1995) to take into account Transit New Zealand's 100 year design life requirement;
- a more comprehensive investigation of the durability of concrete bridges proposed as an extension of this brief position paper. This research would be based on consultation with Transit New Zealand regional offices to identify what concrete durability problems are encountered, how the problems were identified, what remedial measures were used to solve these problems and how they performed. This work would also address regional variations in bridge inspection, data collection and storage systems with a view to Transit New Zealand adopting a common bridge maintenance database system.

General concrete durability research is also carried out by a small number of research agencies who bid competitively for government research monies administered by the Foundation for Research, Science and Technology.

9. REFERENCES

American Association of State Highway and Transportation Officials (1993): "Rapid Determination of the Chloride Permeability of Concrete", AASHTO T277.

Standards Association of Australia (1992): "Methods of Testing Concrete. Method 13 : Determination of the Drying Shrinkage of Concrete for Samples Prepared in the Field or in the Laboratory", AS 1012.13.

Standards Association of New Zealand (1987): "Specification for Concrete Construction", NZS 3109.

Standards Association of New Zealand (1995): "Concrete Structures Standard, Part 1 - The Design of Concrete Structures", NZS 3101.

Transit New Zealand (1991a): "Bridge Inspection and Maintenance Manual", Wellington, New Zealand.

Transit New Zealand (1991b): "Bridge Inspection Policy", TNZ S/6, Wellington, New Zealand.

Transit New Zealand (1991c): "Maintenance Guidelines for State Highways", Wellington, New Zealand.

Transit New Zealand (1991d): "Bridge Manual", Wellington, New Zealand.

UK Department of Transport (1983): "Bridge Inspection Guide", HMSO, London.

APPENDIX 2

DURABILITY OF NEW ZEALAND CONCRETE ROAD BRIDGES

Questionnaire for Postal Survey

SURVEY

DURABILITY OF NEW ZEALAND CONCRETE ROAD BRIDGES

This survey has two principal aims:

- To assess the current condition of New Zealand concrete road bridges and the principal durability problems affecting them.
- To identify the measures taken to assess and remedy these durability problems.

Please use additional pages as necessary to elaborate on any comments.

1(a) Which of the following design and construction-related defects affect your **pre-1960** concrete bridges?

Please rank in order of increasing frequency of occurrence using the following ranking:

1 Affects less than 20% of bridges (occurs rarely or not at all)
2 Affects 20-39% of bridges
3 Affects 40-59% of bridges
4 Affects 60-79% of bridges
5 Affects 80-100% of bridges (occurs frequently)

		Frequency of Occurrence (Tick Where Applicable)				
	Don't Know	1 Rarely	2	3	4	5 Frequently
Voids in concrete / bony concrete	☐	☐	☐	☐	☐	☐
Lack of effective dripformers	☐	☐	☐	☐	☐	☐
Deck joints/deck drains directing water over concrete surfaces	☐	☐	☐	☐	☐	☐
Cracking in deck soffits (uniformly distributed continuous linear cracking)	☐	☐	☐	☐	☐	☐

1(b) Which of the following design and construction-related defects affect your **post-1960** concrete bridges?

Please rank in order of increasing frequency of occurrence using the guidelines given in Question 1(a).

	Don't Know	Frequency of Occurrence (Tick Where Applicable) 1 Rarely	2	3	4	5 Frequently
Voids in concrete / bony concrete	☐	☐	☐	☐	☐	☐
Lack of effective dripformers	☐	☐	☐	☐	☐	☐
Deck joints/deck drains directing water over concrete surfaces	☐	☐	☐	☐	☐	☐
Cracking in deck soffits (uniformly distributed continuous linear cracking)	☐	☐	☐	☐	☐	☐

2(a) Which of the following affect your **pre-1960** concrete bridges?

Please rank in order of increasing frequency of occurrence using the guidelines given in Question 1(a).

	Don't Know	Frequency of Occurrence (Tick Where Applicable) 1 Rarely	2	3	4	5 Frequently
Random / map cracking	☐	☐	☐	☐	☐	☐
Linear cracking	☐	☐	☐	☐	☐	☐
Spalling due to corroding reinforcement	☐	☐	☐	☐	☐	☐
Surface scaling	☐	☐	☐	☐	☐	☐
Poorly performing deck joints	☐	☐	☐	☐	☐	☐
Blocked drains	☐	☐	☐	☐	☐	☐
Handrail failures / defects	☐	☐	☐	☐	☐	☐
Service ducts / attached services (e.g. corrosion of fasteners, ponding, debris accumulation)	☐	☐	☐	☐	☐	☐

2(b) Which of the following affect your **post-1960** concrete bridges?

Please rank in order of increasing frequency of occurrence using the guidelines given in Question 1(a).

	Don't Know	Frequency of Occurrence (Tick Where Applicable) 1 Rarely	2	3	4	5 Frequently
Random / map cracking	☐	☐	☐	☐	☐	☐
Linear cracking	☐	☐	☐	☐	☐	☐
Spalling due to corroding reinforcement	☐	☐	☐	☐	☐	☐
Surface scaling	☐	☐	☐	☐	☐	☐
Poorly performing deck joints	☐	☐	☐	☐	☐	☐
Blocked drains	☐	☐	☐	☐	☐	☐
Handrail failures / defects	☐	☐	☐	☐	☐	☐
Service ducts / attached services (e.g. corrosion of fasteners, ponding, debris accumulation)	☐	☐	☐	☐	☐	☐

3(a) Are these problems particularly common in **pre-1960** concrete bridges of the following type or location?

Please tick where appropriate.

	Bridge Type			**Bridge Location**	
	Cast In Situ	**Cast In Situ Prestressed**	**Precast Prestressed**	**Coastal or Affected by Onshore Winds**	**Inland**
Random/map cracking					
Linear cracking					
Spalling due to corroding reinforcement					
Surface scaling					
Poorly performing deck joints					
Blocked drains					
Handrail failures/defects					
Surface erosion					
Service ducts/attached services					

3(b) Are these problems particularly common in **post-1960** concrete bridges of the following type or location?

Please tick where appropriate.

	Bridge Type			**Bridge Location**	
	Cast In Situ	**Cast In Situ Prestressed**	**Precast Prestressed**	**Coastal or Affected by Onshore Winds**	**Inland**
Random/map cracking					
Linear cracking					
Spalling due to corroding reinforcement					
Surface scaling					
Poorly performing deck joints					
Blocked drains					
Handrail failures/defects					
Surface erosion					
Service ducts/attached services					

4. How often do you carry out the following maintenance activities?

	Estimate of Frequency (e.g. once per year)
Removal of flood debris from waterways	______________
Clearing deck channels	______________
Cleaning deck drains	______________
Maintenance of handrails	______________
Maintenance of deck joints	______________
Graffiti removal	______________
Reinstatement of signs	______________

Other (give details)

____

____

____

5. How often do you inspect your concrete bridges?

Please describe your inspection programme.

6. Do you use a standard form or spreadsheet to record observations made during inspection?

Yes / No (Please circle as appropriate)

7. (a) Are the observations and results of your routine inspection stored electronically?

Yes / No (Please circle as appropriate)

(b) If yes, what database or spreadsheet package do you use?

What do you use this stored information for?

7. (c) If no, would you find such a system useful?

Yes / No (Please circle as appropriate)

Comments:

8. We are trying to quantify how much it costs to maintain the New Zealand concrete bridge stock. Please indicate the approximate amount spent annually on the following:

	Amount Spent Annually ($)
Regular inspection	
Routine maintenance	
Specialist investigation	
Major repair and rehabilitation	
Total	

9. How common is deterioration due to reinforcement corrosion on bridges you administer?

	Don't Know	Affects up to 20% of Bridges	Affects 20-39% of Bridges	Affects 40-59% of Bridges	Affects 60-79% of Bridges	Affects 80-100% of Bridges
(tick where appropriate)	☐	☐	☐	☐	☐	☐

10. What defects would you consider to indicate that reinforcement corrosion is occurring?

11. When you discover these defects, what do you do?

(a) Repair them without further investigation Yes / No

(b) Initiate further investigation Yes / No

If yes, elaborate:

12. What methods have you used to repair concrete affected by reinforcement corrosion?

	Tick Where Applicable
Epoxy mortars	☐
Proprietary cement-based repair materials (applied pneumatically or by hand)	☐
Site mixed cement-based mortar and concrete (applied pneumatically or by hand)	☐
Other (please specify)	☐

____

____

____

13. Why have you used these methods?

Tick where applicable (more than one tick/repair material if appropriate)

	Epoxy Mortar	**Proprietary Cement-Based Repair Materials**	**Site Mixed Cement-Based Mortar and Concrete**	**Other (as above)**
Cost				
Convenience/Availability				
Familiarity/Habit				
Long Term Durability				
Other (please specify)				

14. How did you judge their performance?

	Successful? (please circle as appropriate)	How Judged (please describe)
Epoxy mortar	Yes / No	
Proprietary cement-based repair materials	Yes / No	
Site mixed cement-based mortar and concrete	Yes / No	
Other	Yes / No	

15. Which of these electro-chemical repair techniques are you familiar with?

(tick where applicable)

Cathodic Protection ☐
Realkalisation ☐
Desalination ☐

16 Have you considered using electro-chemical repair techniques for repair of concrete bridges?

Yes / No (Please circle as appropriate)

Why?

17. Please provide any further comments on the topic of concrete bridge durability, including information on specific bridge rehabilitation projects.

DETAILS OF PERSON COMPLETING QUESTIONNAIRE

Name: ______________________________

Position: ______________________________

Organisation: ______________________________

Completion of this survey will be a valuable contribution to the outcome of this research project. The responses made by organisations and their representatives will not be able to be identified in the research report.

Please return by **Friday 24 October** in the stamped self-addressed envelope to:

Opus International Consultants Ltd
Central Laboratories
P O Box 30-845
LOWER HUTT

Attention: Sheldon Bruce

If you have any queries about the questionnaire, please contact:

Sheldon Bruce
Phone (04) 568-3119
Fax (04) 568-3169

APPENDIX 3

100-YEAR DESIGN LIFE PROPOSAL

for use in Bridge Inspection & Maintenance Manual
(Transit New Zealand 1991)

OPUS
INTERNATIONAL
CONSULTANTS

29 July 1997

Mr Frank McGuire

Transit New Zealand
PO Box 5084
Wellington

Transit New Zealand Bridge Manual - Concrete Durability

Ref: 5C2728.00

Dear Sir

In response to your request for an interim "quick fix" to provide guidance to designers on provision for durability to achieve the specified 100 year design life, the appended table of minimum concrete strengths and covers for the various environmental categories is proposed for use in conjunction with application of the other requirements of NZS 3101.

This table has been derived from a review of NZS 3101 and the following international bridge design codes:

-	'92 Austroads Bridge Design Code	- which is based on a 100 year design life
-	BS 5400	- which is based on a 120 year design life
-	AASHTO 7th Edition, 1996	- does not contain a statement of design life basis
-	Ontario Highway Bridge Design Code, 3rd Edition, 1991	- does not contain a statement of design life basis

While the ASSHTO and OHBDC do not set out their design life basis, we judge that their life expectation for their bridges would be similar to that adopted in New Zealand, and as highly recognised codes, they should be considered .

The proposed table envelopes the cover requirements set out in NZS 3101 and the Austroads Code, except as noted below. As best can be judged from the varying descriptions of environmental conditions, and with consideration given to de-icing salts not being commonly employed on roads in New Zealand, these covers are generally equivalent to or more conservative than those adopted by the other bridge design codes for the case of standard formwork and standard compaction.

The Austroads Code, in exposure categories B1 and B2, does not allow use of concrete of strength less than 32 MPa and 40 MPa respectively. In New Zealand lower concrete strengths in these exposure categories need to be accepted to cater for site batching in remote locations. Covers proposed for these exposure categories, for concrete strengths below these limits, are based on work by RD Browne "Durability of Reinforced Concrete Structures", with some smoothing and rounding of the values.

The NZS 3101 requirements "apply to the detailing and specifying for durability of reinforced and prestressed concrete structures and members with a specified intended life of 50 years." That is not to say that the NZS 3101 requirements would not provide durability for longer intended lifes.

The Austroads Code requirements "apply to plain, reinforced and prestressed concrete structures and members with a design life of 100 years. ... It is intended to apply to bridges with a normal life span." The Austroads Code commentary defines a structure's durability as the "the ability to withstand the expected

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wear and deterioration throughout its intended life without the need for undue maintenance." This is reasonably compatible with the Building Code requirements.

The proposed table represents our judgement of the concrete strength and cover provisions necessary, in addition to satisfaction of the other requirements of NZS 3101, to provide reasonable assurance that the durability requirements of the Building Code would be satisfied for a 100 year design life. Opus International Consultants has based this on currently accepted international practice.

We recommend that Transit New Zealand circulate this proposal to key players in the industry (ie, design consultants, concrete suppliers, universities and research institutions) and seek support for the proposed table prior to promulgation. The feedback so gained may also be a highly beneficial input in initiating research to substantiate the table values.

Yours faithfully
Opus International Consultants Limited

Donald Kirkcaldie

Donald Kirkcaldie

Proposed Minimum Required Concrete Covers for Transit NZ Bridges

The following tables are proposed as a replacement for NZS 3101:Part1:1995 Table 5.5. The following covers apply to concrete construction incorporating type GP Portland cement complying with NZS 3122. Concrete construction incorporating alternative cement types are not covered by the following tables and shall be evaluated to establish their peformance. The following tables also do not apply to concrete construction where protective coatings are applied. Exposure classifications are as defined in NZS 3101 Section 5, and in all other respects the durability requirements of NZS 3101 Section 5 shall apply.

Table A *Standard Formwork and Standard Compaction* *

Exposure Classification	*Specified compressive strength f'c* 25	30	40	50
	Minimum required cover (mm)			
A1	30	25	20	20
A2	35	30	25	25
B1	50	40	35	30
B2	65	60	50	40
C**				70
Cast in contact with non-aggressive ground	75	75	75	75
Cast with DPC in contact with non-aggressive ground	50	50	50	50

Table B *Precast Construction with Rigid Formwork and Intense Compaction* *

Exposure Classification	*Specified compressive strength f'c* 25	30	40	50
	Minimum required cover (mm)			
A1	25	20	20	20
A2	35	30	25	25
B1	45	35	30	30
B2	55	50	40	35
C**				70

* Standards of formwork and compaction are as adopted by the '92 Austroads Bridge Design Code (refer clause 5.4.10.3), ie :

Table A shall apply where concrete is cast in formwork complying with AS 3610 and is transported, placed and compacted so as to :

- limit segregation or loss of materials;
- limit premature stiffening;
- produce a monolithic mass between planned joints the extremities of members or both
- completely fill the formwork to the intended level, expell entrapped air and closely surround all reinforcement, tendons, ducts, anchorages and embedments; and
- provide the specified finish to the formed areas of the concrete.

Table B shall apply where the concrete is cast in rigid forms and subjected to intense compaction, such as obtained with vibrating tables or form vibrators.

** In addition to the specified cover, a type GP Portland cement content of 350 kg/m^3 and water cement ratio not exceeding 0.4 is required