2 Design - General Requirements

Table of Contents

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2.1 Design Philosophy

2.1.1 General

Bridges shall be designed to satisfy the requirements of both the ultimate and the serviceability limit states when acted on by any of the combinations of loading defined in this document.

During the design process all relevant factors affecting the design, such as those listed in broad terms in 1.3(b), shall be taken into account to ensure compliance with all relevant legislation and regulations, including the Resource Consent for the project and the *New Zealand Building Code Handbook*(1). Detailing shall be such that it promotes ease of construction and ease of maintenance.

Construction methods shall be considered, in order to avoid undue expense due to unnecessarily complicated procedures. However, methods shall not be specified unless they contain features essential to the design assumptions.

2.1.2 Definition of Terms

Serviceability Limit State: The state at which a structure becomes unfit for its intended use through deformation, vibratory response, degradation, or other operational inadequacy.

Ultimate Limit State: The state at which the strength or ductility capacity of the structure is exceeded, or when it cannot maintain equilibrium and becomes unstable.

Design Working Life: The design working life of a bridge is that life beyond which the bridge will be expected to have become functionally obsolete or to have become uneconomic to maintain in a condition adequate for it to perform its functional requirements.

Major Renovation: Major renovation is maintenance work necessary to maintain the strength, ductility capacity, or serviceability of a bridge to enable it to fulfill its functional requirements, which exceeds 20% of the replacement value of the bridge.

2.1.3 Basis of Design

Design to this document is based on limit state principles adopting where possible a statistical approach to the derivation of design loads and material strengths.

Design actions other than earthquake, wind, snow and floodwater are based on a statistical distribution appropriate to a 100 year design working life. Where statistical distributions are not available, design actions are based on judgment and experience. For dead and live load, the target probability of exceedance within 100 years that has been adopted is 5%.

For wind, snow and flood water actions, bridges shall be categorised into an importance level for which the assigned annual probabilities of exceedance for these actions shall be as given in Table 2.1. Refer to 2.1.6 for definitions of the ultimate and serviceability limit states. The bridge shall remain operationally functional following flood events up to an SLS I event, and both the structure and non-structural elements shall remain undamaged following wind, snow and flood events up to an SLS II event. SLS I and SLS II events are serviceability limit state events defined by the annual probabilities of exceedance given in Table 2.1(a) and 2.1(b). Earthquake actions are included in Section 5: Earthquake Resistant Design.

Table 2.1: Importance Level and Annual Probabilites of Exceedance for Wind, Snow and Floodwater Actions

Bridge Usage	Importance Level (as per AS/NZS 1170)	Bridge Permanence*	Annual Probability of Exceedance for the Ultimate Limit State	Annual Probability of Exceedance for the Serviceability Limit State	
				SLS I for Flood Water Actions	SLS II
Bridges of high importance to post-disaster recovery (e.g. bridges in major urban areas providing direct access to hospitals and emergency services, or to a port or airport from within a 10 km radius.) Bridges with a construction cost exceeding $10 million (as at 2004)	4	Permanent	1/5000	1/100	1/25
		Temporary	1/1000	1/100	1/25
Bridges on the primary lifeline routes identified in Figure 2.1(a), 2.1(b), and 2.1(c), categorised on the basis of • volume of traffic carried • route strategic importance (e.g. inter-connection of centres of population) • redundancy of the regional roading network	3	Permanent	1/2500	1/100	1/25
		Temporary	1/500		1/25
Normal bridges, not falling into other levels	2	Permanent	1/1000	1/50	1/25
		Temporary	1/250		1/25
Bridges on no-exit or loop rural roads, not serving a through road function, and serving populations <50 Footbridges	1	Permanent	1/500	1/25	1/25
		Temporary	1/25		

* Permanent bridge: design working life = 100 years
Temporary bridge: design working life ≤ 5 years

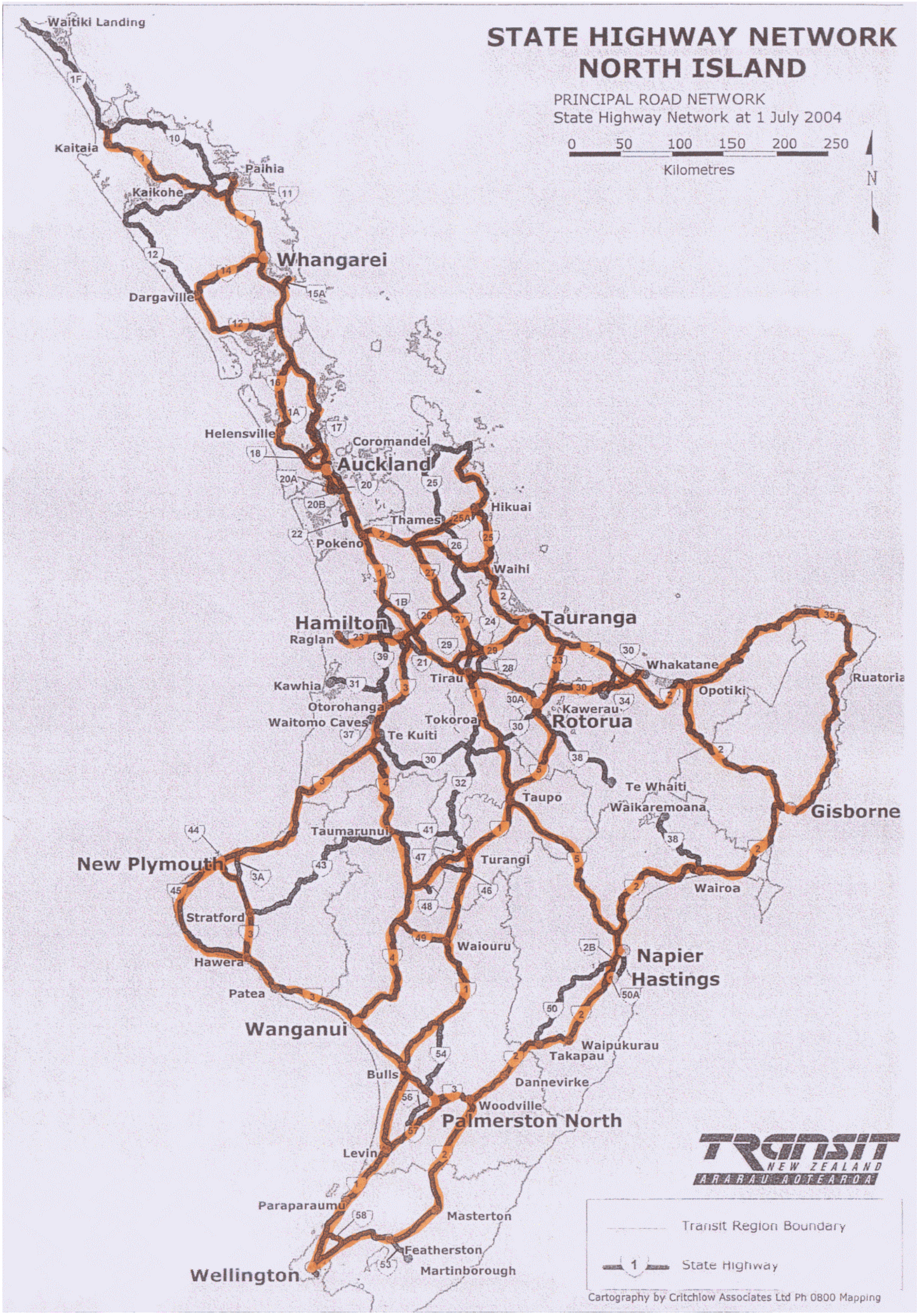

Figure 2.1(a): North Island Importance Level 3 Routes (shown in orange)

Figure 2.1(b): South Island Importance Level 3 Routes (shown in orange)

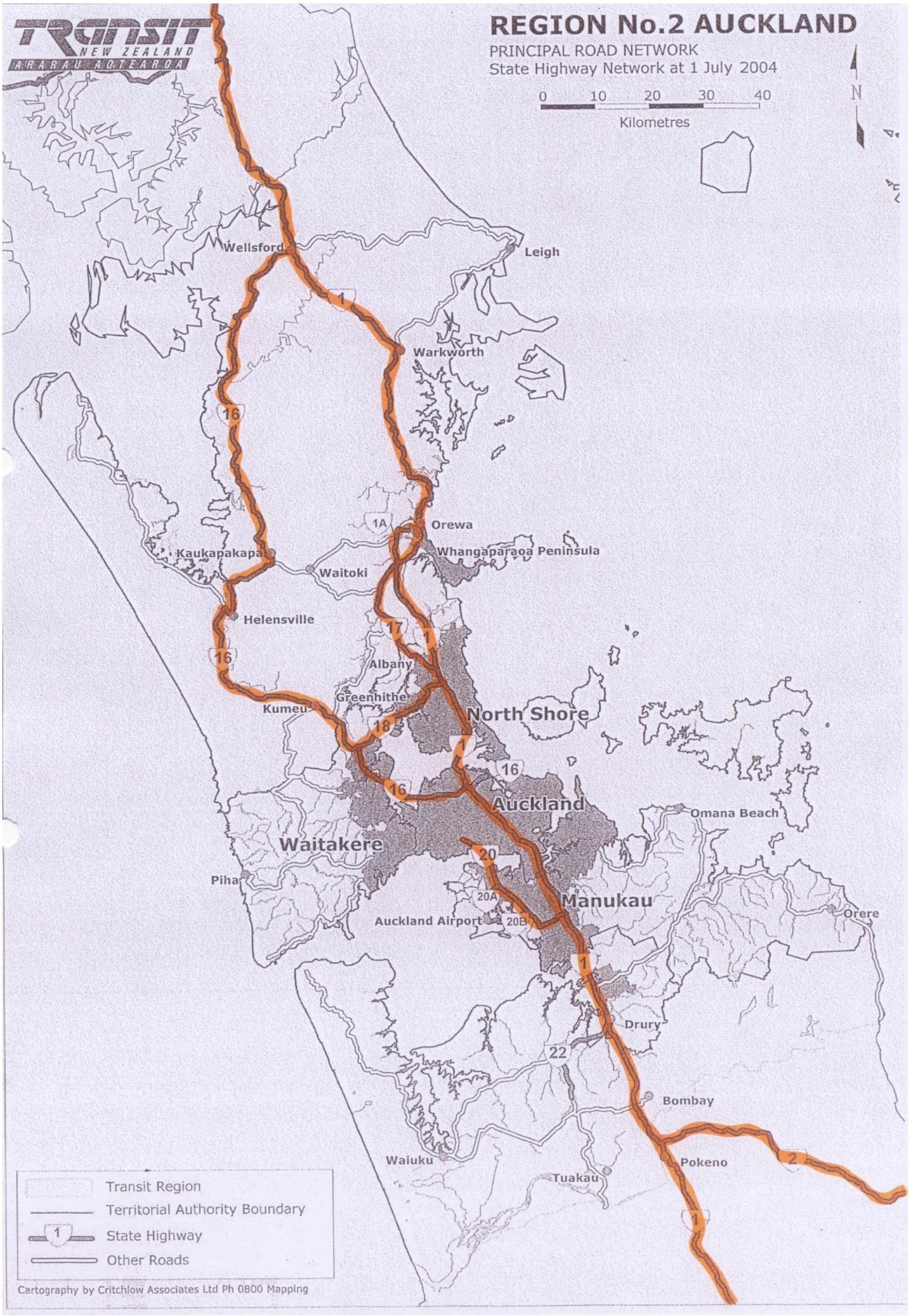

Figure 2.1(c): Auckland Region Importance Level 3 Routes (shown in orange)

2.1.4 Design Codes

This document defines design loadings, load combinations and load factors, together with criteria for earthquake resistant design, and other miscellaneous items. It does not define detailed design criteria for the various materials, but refers to standard codes such as those produced by Standards New Zealand, Standards Australia and the British Standards Institution. The standards referred to shall be the editions referenced, including all current amendments. The specified portions of these standards are to be read as part of this document, but any references in such standards to specific loads or load combinations shall be disregarded.

2.1.5 Design Working Life Requirements

For the purpose of assessing probabilistic effects of loading such as wind, earthquake, flood and live load fatigue, and for consideration of long term effects such as corrosion, creep and shrinkage, the design working life of a bridge is assumed to be 100 years in normal circumstances. This may be varied by the controlling authority if circumstances require it, for example for temporary structures or for strengthening of existing structures. It should be noted that the 100 year design working life exceeds the minimum requirement of the *New Zealand Building Code Handbook*(1) and the design life adopted as the basis for durability requirements by Standards New Zealand materials design standards.

2.1.6 Limit State Requirements

Serviceability Limit State: The structure and its component members shall be designed for the serviceability limit state by limiting deflection, vibration, cracking and structural damage, as appropriate, providing adequate durability, and maintaining operational function in accordance with the requirements of this document and the material design standards referred to in this document.

Ultimate Limit State: The structure and its component members shall be designed for the ultimate limit state by providing adequate strength and ductility, ensuring stability, and providing adequate durability, in accordance with the requirements of this document and the material design standards referred to in this document.

2.1.7 Durability Requirements

The structure and its component members shall be designed to provide adequate durability in accordance with the requirements of the material design codes, except where specific requirements are included in this document, which shall take precedence.

Structures shall be sufficiently durable to ensure that, without reconstruction or major renovation, they continue to fulfill their intended function throughout their design life.

2.1.8 Structural Robustness

All parts of the structure shall be interconnected, in both horizontal and vertical planes, to provide the structure with the robustness to adequately withstand unanticipated extreme loading events such as extreme flood, earthquake or vehicle collision.

The Designer, in detailing the various elements of a structure, shall consider the effect of that detailing on the robustness of the structure as a whole to unanticipated extreme loading events and seek to ensure robustness of the structure.

2.2 Geometric and Side Protection Requirements

Roadway and footpath widths and horizontal and vertical clearances shall comply with Appendix A as a minimum.

(a) Side protection to all new bridges, and where it is decided to replace side protection on existing bridges, shall be provided in accordance with the requirements of AS/NZS 3845 *Road Safety Barrier Systems*(2) as implemented by TNZ M/23 *Specification for Road Safety Barrier Systems*(3) and modified by Appendix B of this manual.

(b) Side protection is defined as the rail or barrier systems by which users of the bridge are restrained from leaving the area of deck or approach roadway allotted to them. A risk management approach to side protection selection is described in Appendix B, Clause B2. Means of compliance with the requirements, which are mandatory for Transit New Zealand funded work, are given in Clauses B3 to B5.

(c) Clearances over railways shall comply with the requirements of Tranz Rail Limited and other network operators.

2.3 Waterway Design

2.3.1 General

The waterway design of bridges and culverts shall comply with the requirements of the Austroads publication: *Waterway Design – A Guide to the Hydraulic Design of Bridges, Culverts and Floodways*(4) except as amended below:

2.3.2 Design Floods

(a) General

Waterway Design – A Guide to the Hydraulic Design of Bridges, Culverts and Floodways(4) provides recommendations for the recurrence intervals of the floods that should be used for the various aspects of design, but does not provide specific standards, instead leaving these to roading authorities to define. This clause details Transit New Zealand's standards for the recurrence intervals of floods for waterway design.

In designing a stream crossing, consideration should be given to the type of structure, typically a bridge or culvert, and to the impact of the structure on the waterway and surrounding environment, due to the structure and its approaches.

(b) Overall Design of Total Waterway

In the design of a stream crossing, the total waterway shall be designed to pass a 100 year Average Recurrence Interval (ARI) flood without significant damage to the road and waterway structure(s). The Regional Council or Territorial Authority responsible for the waterway shall be consulted to determine if the waterway needs to be designed for a flood greater than the 100 year ARI event. Although the minimum total waterway design flood is a 100 year ARI event, the Level of Serviceability to Traffic may provide for the crossing to be impassable with a lower ARI flood.

(c) Serviceability Limit State

Level of Serviceability to Traffic: State highway stream crossings shall pass floods of the ARI corresponding to the annual probability of exceedance for the SLS I given in Table 2.1 without interruption or disruption to traffic.

(ARI = 1/(annual probability of exceedance))

Damage Avoidance: Bridges shall be designed to withstand the effects of a 25 year ARI flood without sustaining damage.

(d) Ultimate Limit State

For the Ultimate Limit State, bridges shall be designed for the effects of the ARI flood corresponding to the importance of the bridge and the annual probability of exceedance given in Table 2.1.

In situations where the design flood for the Ultimate Limit State will substantially overtop the bridge structure, the design engineer shall also investigate the intermediate stages in the flood height and consider those stage heights that are most critical.

2.3.3 Hydrology

(a) Flood Estimation Methods

The following two methods replace the methods outlined in Section 3 of *Waterway Design – A Guide to the Hydraulic Design of Bridges, Culverts and Floodways*(4):

- The Rational Method – in which a peak flow of a selected ARI is estimated from the average rainfall intensity of the same ARI.
- The Regional Method - *Flood Frequency in New Zealand*(5) by McKerchar and Pearson.

(b) Rational Method

The Rational Method is only applicable to small catchments, because of its inability to account for the effects of catchment storage in attenuating the flood hydrograph. The recommended maximum size of the catchment to which the method should be applied is 25 km^2 in urban catchments, and between 3 and 10 km^2 for rural catchments. The Rational Method is described in *Australian Rainfall and Runoff*(6) and the *Handbook of Hydrology*(7).

(c) Regional Method

Flood Frequency in New Zealand(5) is a regional method suitable for all rural catchments except those in which there is snow-melt, glaciers, lake storage or ponding. It should be used for rural catchments greater than 10 km^2, and can also be used for rural catchments between 3 km^2 and 10 km^2, but should be checked against the Rational Method.

(d) For Catchments Other Than Those Covered by (b) and (c) Above

For catchments other than those covered by (b) and (c) above, the determination of design floods should be the subject of detailed hydrological investigation.

(e) Estimation of the Ultimate Limit State Design Flood

The estimation of the ULS design flood shall be made based on a probability analysis of available data using more than one recognised probability analysis method. Wherever possible the data shall be obtained from a hydrology flow station at or near the site of the proposed bridge. Recognised probability analysis methods include the Gumbel, Log Pearson and Generalised Extreme Value (GEV) methods. Probability analysis methods are described in the *Handbook of Hydrology*(7). It should be noted that predictions beyond the 100 year ARI are not precise and estimates for the ULS event shall be checked against other nearby gauging stations and information from other nearby catchments and rivers.

If there is no hydrology flow information available at the bridge site, then an upstream site on the same river, or alternatively a gauging site on a nearby river with similar hydrological characteristics, should be used. Data from more than one site should be used to ensure that a degree of smoothing of extreme values occurs. Scaling of flood flows should be performed to adjust for differences in catchment areas. Flood flows should be scaled by the ratio of the catchment area to the power 0.8, as discussed in *Flood Frequency in New Zealand*(5), Section 3 - Mean Annual Floods, i.e.

$$Q_1 / Q_2 = (A_1 / A_2)^{0.8}$$

where Q is the flood discharge and A is the catchment area.

2.3.4 Hydraulics

(a) Freeboard for Level of Serviceability to Traffic

When considering the Level of Serviceability to Traffic required by 2.3.2 (c), the following freeboards given in Table 2.2 shall be used.

Table 2.2: Freeboard Allowance for the Level of Serviceability to Traffic

Waterway Structure	Situation	Freeboard	
		Measurement Points	Depth (m)
Bridge	Normal circumstances	From the predicted flood stage to the underside of the superstructure	0.6
	Where the possibility that large trees may be carried down the waterway exists		1.2
Culvert	All situations	From the predicted flood stage to the road surface	0.5

(b) Waterways

In low-gradient silt- and sand-bed rivers, determinations of Manning's *n* from sets of photographs, for example, from *Roughness Characteristics of New Zealand Rivers*(8), or from tables of values such as Table 4.1 of *Waterway Design – A Guide to the Hydraulic Design of Bridges, Culverts and Floodways*(4), should be taken as approximate only. Any possible backwater effects from downstream features should be investigated. Direct measurements should be obtained whenever possible.

In gravel-bed rivers, estimates of Manning's *n* shall be made using at least one formula, (for example, one of the "rigid bed" formulae by Griffiths, refer (c) below), as well as using *Roughness Characteristics of New Zealand Rivers*(8). *Waterway Design – A Guide to the Hydraulic Design of Bridges, Culverts and Floodways*(4), Table 4.1 is not appropriate to New Zealand rivers with gravel beds and shall not be used. If the formula in *Open Channel Flow*(9) is used, a factor of 1.2 should be applied to the calculated values of Manning's *n*.

In all other rivers, the estimation of Manning's *n* shall be the subject of a detailed hydraulic investigation.

(c) Griffiths Formulae

The Griffiths formulae noted above are taken from *Flow Resistance in Coarse Gravel Bed Rivers*(10). The two "rigid-bed" formulae recommended by Griffiths are:

$$1/\sqrt{f} = 1.33(R/d_{50})^{0.287}$$

$$1/\sqrt{\mathrm{f}} = 1.98\log_{10}(\mathrm{R}/\mathrm{d}_{50}) + 0.76$$

where f is the Darcy-Weisbach friction factor, R is the hydraulic radius and d_{50} is the size for which 50% of the bed material is smaller. f is related to Manning's n by the following formula:

$$n = 0.113\sqrt{f}R^{1/6}$$

2.3.5 Scour

The estimation of scour should be based on the *Bridge Scour Monograph*(11). This publication replaces section 6 of *Waterway Design – A Guide to the Hydraulic Design of Bridges, Culverts and Floodways*(4).

2.4 Site Investigations

All bridge sites shall be subject to appropriate geotechnical and geological investigations, sufficient to ensure that a safe, economical and practical design can be developed. The investigations shall establish the characteristics of the surface and subsurface soils, their behaviour when loaded, the nature and location of any faulting, and the groundwater conditions. Site conditions and materials affecting the construction of the structure shall also be determined.

Investigations normally consist of three phases:

(a) Preliminary investigations, consisting of compilation of general data, walkover survey, and where appropriate, some boreholes and laboratory tests.

(b) Detailed field investigations and laboratory tests usually after completion of the Design Statement and before final design.

(c) Investigations during construction, as appropriate.

Information obtained from site investigations shall be presented in an Investigation Report. Borelogs, soil descriptions and testing shall comply with current practice, as presented in documents published by Standards New Zealand, New Zealand Geotechnical Society, or similar. These investigations shall include interpretation of all available data by suitably qualified personnel, and recommendations as to foundation types and design parameters, and the need for proof testing, pilot drilling or other confirmatory investigation during construction.

2.5 Influence of Approaches

The designer shall consider the influence of approach embankments and cuttings on the bridge structure, including:

- immediate gravity effects;
- seismic effects;
- long term settlement effects;
- loading from slope material, which may fall onto the deck.

The effects of approach settlement and stability on the riding characteristics, traffic safety and performance of abutment components shall be considered.

2.6 Aesthetics

The designer shall give careful consideration to the aesthetics of the structure. Guidance on the principles involved may be obtained from the following references:

- Fédération Internationale du Béton publication: *Guidance for Good Bridge Design*(12)
- Hong Kong Government Highways Department publication: *Structures Design Manual for Highways and Railways*(13) (available from the internet website: http://www.hyd.gov.hk/publications/index.htm - Chapter 17, Figures 21 – 29 and Plates 1 - 11).
- UK Department of Transportation Advice Note: BA 41/98, *The Design and Appearance of Bridges*(14).
- UK Highways Agency publication: *The Appearance of Bridges and Other Highway Structures*(15).

2.7 Special Studies

Special studies are required when:

- A structural form or method of construction is proposed which is not covered by accepted standards or design criteria (eg. to determine design parameters, safety factors or durability).
- New materials are to be applied, the technology of which is still undergoing significant development.

Special studies shall be documented in complete reports, included as Appendices to the Design Statement. This documentation shall include, as appropriate:

- The source of all data.
- Demonstration that the study has provided appropriate evaluation of the particular structural performance being investigated.
- Reference to relevant national and international standards and guidelines, and published peer reviewed papers.
- Comparison of the results with other data.
- A description of the analytical methods used.

2.8 References

(1) BIA, 1992, *New Zealand Building Code Handbook*, Building Industry Authority, Wellington.
(2) AS/NZS 3845, 2002, *Road Safety Barrier Systems*, Standards Australia and Standards New Zealand, jointly.
(3) TNZ M/23, 2002, *Specification for Road Safety Barrier Systems*, Transit New Zealand.
(4) Austroads, 1994, *Waterway Design – A Guide to Hydraulic Design of Bridges, Culverts and Floodways*, Austroads Inc., Sydney.
(5) McKerchar, A.I., Pearson, C.P., 1989, *Flood Frequency in New Zealand*, Hydrology Centre Publication 20, Hydrology Centre, DSIR Division of Water Sciences, Christchurch.

(6) IEA, 1987, *Australian Rainfall and Runoff*, Volume 1, Institution of Engineers Australia.

(7) Maidment, D.R., 1993, *Handbook of Hydrology*, McGraw- Hill Inc.

(8) Hicks, D.M., Mason, P.D., 1991, *Roughness Characteristics of New Zealand Rivers*, DSIR Marine & Freshwater, Wellington

(9) Henderson, F.M., 1996, *Open Channel Flow*, MacMillan, New York.

(10) Griffiths, G.A., 1981, *Flow Resistance in Coarse Gravel Bed Rivers*, Proc. ASCE 107HY7, pp 899-918.

(11) Melville, B., Coleman, S., 2000, *Bridge Scour Monograph*, Water Resources Publications, LLC.

(12) FIB, 2000, *Guidance for Good Bridge Design,* Fédération Internationale du Béton, Lausanne, Switzerland.

(13) ____, 1997, *Structures Design Manual for Highways and Railways*, (2nd Ed.), Hong Kong Government Highways Department (available from the internet website: http://www.hyd.gov.hk/publications/index.htm - Chapter 17, Figures 21 – 29 and Plates 1 - 11).

(14) DOT (UK), 1998, *The Design and Appearance of Bridges,* UK Department of Transportation Advice Note: BA 41/98.

(15) ____, 1996, *The Appearance of Bridges and Other Highway Structures*, The Highways Agency, London.