A FRAMEWORK FOR AN IDEAL ROAD STRUCTURES DESIGN MANUAL

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D K KIRKCALDIE
Works Consultancy Services Limited
Wellington, New Zealand

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P O Box 2331, Lambton Quay, Wellington, New Zealand
Telephone (04) 473-0220; Facsimile (04) 499-0733

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EXECUTIVE SUMMARY

1 Background

The '92 Austroads Bridge Design Code is being used as a base document for development of a proposed joint Australia / New Zealand bridge design standard. As a consequence, Transit New Zealand commissioned this project to review the Austroads Bridge Design Code for its suitability for use in New Zealand.

During the course of this project the decision was taken by Standards Australia and Standards New Zealand that a joint national bridge design standard would not proceed at this time. This arose primarily as the result of lack of funding priority for this work from New Zealand organisations looked to for support for it.

2 Project Objectives

Objectives of this project have been to:

2.1 Define in broad terms the coverage required of an "ideal" Transit New Zealand bridge code, as a benchmark against which the existing Austroads Bridge Design Code and Transit New Zealand Bridge Manual can be measured, and as a benchmark for future code development;

2.2 Review the '92 Austroads Bridge Design Code and compare with the Transit New Zealand Bridge Manual and recommend which of the two documents should be adopted by Transit New Zealand as the base document for future development and upgrade as Transit New Zealand's design code for bridges;

2.3 Identify significant differences between the '92 Austroads Bridge Design Code and the Transit New Zealand Bridge Manual and identify areas requiring revision in the document recommended by the Consultant for acceptance by Transit New Zealand as their base document for the design of bridges; and

2.4 Identify consequential technical issues arising from adopting in whole or in part of the '92 Austroads Bridge Design Code for Transit New Zealand policy and administration of the national roading asset.

3 Project Outcomes

The project outcomes address the above objectives in order and follow a corresponding numbering sequence:

3.1 To meet Transit New Zealand's needs, it is recommended that the ideal code or design manual encompass the design of all roading structures. The coverage of an ideal road structures design manual should include:

- Code applicability and scope;
- Design objectives, philosophy and basis;
- Project initiation and approval;
- Site information;
- General design criteria (geometric requirements, waterway, etc);
- Design loadings;
- Analysis criteria;
- Materials design criteria;
- Structural elements design criteria;
- Criteria for earthquake resistant design;
- Design criteria for lightly trafficked rural bridges;
- Acceptable solutions for elements for which compliance with the specified performance criteria may be onerous to demonstrate; and
- Structure capacity evaluation.

The document should be a manual providing a full presentation of the design criteria for Transit New Zealand-funded or -subsidised roading structures, encompassing both performance criteria and design criteria derived from Transit New Zealand policy. Consistent with current Transit New Zealand policy, the manual should not prescribe design methods.

3.2 An ideal road structures design manual cannot be created satisfactorily from one of the documents alone, but will require incorporation and significant modification of both documents. Consideration of other sources of information and approaches in developing an ideal manual is also recommended.

The Bridge Manual should be retained in the interim, pending development of an ideal manual. Factors making the Austroads Code unsuitable for adoption in the interim are primarily the significant differences in design traffic loadings, and the omission of comprehensive criteria for earthquake resistant design, steel and composite design, and for capacity evaluation of existing structures. Also, in a number of areas the Austroads Code tends to be prescriptive instead of specifying performance requirements, includes design guidance, or lacks specificity in its requirements. The lack of specificity applies particularly to requirements dependent on roading authority policy.

3.3 Both documents are based on the limit state design philosophy. This philosophy is expressed more consistently and in more up-to-date terminology in the Austroads Code. The Austroads Code introduces a concept of levels of service for some aspects of design, which merits further development and wider application. Expansion of both documents is required to provide comprehensive coverage of all roading structures. Major differences between the two documents have been noted in 3.2 above and 3.4 below. Specific recommendations for each of the range of topics requiring coverage are presented in 5 below.

Materials design sections are included in the Austroads Code, while the Bridge Manual refers to national and international standards for these. Adoption of national standards where possible, and otherwise of international standards for materials design is recommended, to minimise the resources required to maintain the design manual in an up-to-date state and to eliminate inconsistencies as documents are revised.

3.4 There are three key issues affecting Transit New Zealand policy and administration of the roading asset which require detailed review and possible revision.

- The defined basis to be adopted for the limit states. This encompasses the:
  - Definition of design life (as a basis for deriving ultimate limit state and durability criteria);
  - Definition of ultimate limit state and the acceptable probability of it being reached;
  - Definition of serviceability limit state and the acceptable probability of it being exceeded;
  - Definition of required levels of service for various conditions (e.g. traffic load capacity, service availability during flooding, safety barrier and performance);
  - Design load combinations to be applied for the ultimate limit state and for the serviceability limit state; and
  - Interpretation of the Building Code durability requirements.

(These aspects impact on the life expectancy of the structures, their risk of damage and the degree of damage they may expect to sustain, and consequently the ongoing structure maintenance, rehabilitation and replacement costs of the network. This is a fundamental topic of top priority).

- The design traffic loadings and their associated load factors. (These are significantly different between the Austroads Code and the Bridge Manual, and need to reflect projected future amendments to the heavy motor vehicle regulations and trends in levels of enforcement. Changes in these will impact on the life expectancy for existing structures and on the administration of the overweight permit system. This is a major topic of high priority).

- The geometric design standards for structures. (The Australian Code implies greater clearances, and thus wider bridges, than currently required by Transit New Zealand, with obvious cost implications for new construction, if adopted. This is a significant topic but of lesser priority).

4 Recommended Actions

Recommended follow-on actions from this project are as follows:

4.1 That studies be commissioned to resolve the major issues presented in 3.4 above, in the order of priority presented.

4.2 That a policy be formalised on the adoption of national and international materials design standards versus inclusion within the manual of materials design sections (refer to 3.3 above).

4.3 That the existing Bridge Manual be maintained, until there is a commitment to develop an ideal road structures manual and that revisions are progressed based on assigning a priority order to the recommendations set out in 5 below. Implementation of the recommendations below will result in adoption or incorporation of those aspects of the Austroads Code that are considered beneficial and appropriate, thereby reducing the gap between the two documents. This activity should also include monitoring and review of the outcome from Standards Australia's BD/90 bridge code committee's work.

5 Summary of Recommendations on Ideal Manual Format and Contents

Summarised below are recommendations pertaining to the development of the ideal road structures design manual for Transit New Zealand and encompass: which document should be adopted as the base; the manual structure, format, and coverage; the manual philosophy, principles and approach; and recommendations on specific material to be incorporated in each of the topic areas requiring coverage.

5.1 Ideal Manual Development

Development of an ideal road structures design manual should not adopt either the Bridge Manual or the Austroads Code alone as the base, but should be based on a merging and significant modification of both documents.

Where available, national materials design standards should be adopted, or if not available, accepted international materials design standards should be used as the primary basis for materials design.

5.2 Manual Structure Format and Coverage

The recommended coverage of the ideal Transit New Zealand manual is that set out in 3.1.

Retain the current content nature of the Bridge Manual, presenting policy and the design criteria derived therefrom associated with the design of structures, together with performance criteria, in the one document.

It has not been Transit New Zealand policy to provide commentary, but if a Commentary section is included it should be published as a separate volume.

Adopt a format for the text that will allow identification of sections as being referenced by the Building Code Approved Documents, or as being relevant to other legislation or regulations.

Retain the loose leaf ring binder presentation format of the Bridge Manual.

5.3 Manual Philosophy Principles and Approach

5.3.1 Manual Applicability

In addition to a list of structures to which the manual applies, it should include a list of organisations to which it applies. This is expected to influence achievement of Building Industry Authority Approved Document status. The manual should also include a statement of its status under the New Zealand Building Act.

5.3.2 Limit State Basis Design Life and Durability

Undertake a detailed review and clearly define the basis for limit state design. Aspects that need resolution include:

- The intended design life for all types of structures covered by the manual, and whether the same design life should be adopted for structures of the same type but of different importance;
- The accepted probability of exceedance of design loadings and events within the life of the structure;
- The levels of service required of structures. Where possible, these should be quantified, e.g. in terms of probability of exceedance of service loads (damage criterion), and probability of temporary loss of service; and
- Interpretation of the Building Act durability requirements to provide a clear definition of such terms as "reconstruction", "major renovation" and "functional requirements" as they are to be applied to roading structures.

5.4 Bridge Geometry Form and General Aspects

5.4.1 Bridge Geometry

Retain clearance diagrams (as in the Bridge Manual) as a means of portraying both minimum and desirable clearances but also include criteria for the provision of greater clearances where these may be appropriate, setting out factors to be considered (as in the Austroads Code).

Retain the present form of presentation of standard bridge deck cross-sections as presented in the Bridge Manual.

Review and revise the specified clearances to meet current requirements.

Review the setback of barriers and kerbs from the edge of traffic lanes, and the geometric requirements for cycleways contained in the Austroads Code for adoption, noting that their adoption would impact on bridge widths and thus bridge costs.

5.4.2 Pedestrian Bridges and Subways

Review the Austroads Code geometric requirements for pedestrian bridges and subways for adoption and inclusion in the manual.

5.4.3 Waterway Design

Review and develop the Austroads approach to waterway design for use in New Zealand. Resolution is required of the design flood to be adopted for the Ultimate Limit State (ULS) and service levels need to be established.

5.4.4 Safety

Include a statement of the general philosophy and principles to be applied to the safety of users and of the structures. Adopt the Austroads level of service approach for the design of barriers, but add specificity and retain the existing acceptable solutions contained within the Bridge Manual.

5.4.5 Wind and Noise Barriers

Develop and incorporate criteria for the provision and design of wind and noise barriers.

5.4.6 Lighting

Develop criteria for requiring lighting provision, and its design on pedestrian bridges and in pedestrian subways. Review the existing requirements for road carriageway lighting and its adequacy for pedestrians on road bridge footpaths. Include reference to existing documents for design criteria for illumination of bridge carriageways and for performance based criteria for the structural design of lighting supports. Review the joint Australian /New Zealand standard AS/NZS 1158.01 for adoption, when available. As a consequence, review and revise Transit New Zealand's "State Highway Control Manual" and standard specifications M/18P:1990 and M/19:1994 as necessary.

5.4.7 Trafficked Surfaces

Develop and include criteria pertaining to: texture and wearability of surfaces trafficked by vehicles or pedestrians; surface compatibility with approaches; and icing mitigation.

5.4.8 Drainage

Merge the drainage requirements of the Bridge Manual and Austroads Code to provide a more comprehensive coverage of this topic. Expand the criteria and add specificity in respect to design of drainage systems. Consider the need for provisions catering for implications arising from the application of the Resource Management Act to water discharged from bridge decks.

5.4.9 Durability

Review the Austroads requirements for durability for adoption. Retain consideration of whole of life costs, but this consideration needs to be made subordinate to satisfying the Building Act durability requirements.

5.4.10 Aesthetics

Include criteria for consideration of aesthetics, particularly for bridges that are prominent or in an urban environment.

5.4.11 Deformations

Include a statement of the general principles applying to the consideration of deformations. Undertake a detailed review of the Austroads Code and Bridge Manual criteria to determine which are the more appropriate. Include criteria for superstructure deflection under dead load and long term creep in concrete bridges.

5.4.12 Access and Maintenance

Include requirements for access and maintenance. The Austroads Code provides the better basis for these, but they should be extended to provide for maintenance of shear keys, drainage systems, services, and for access into internal voids. Consider the need for requirements related to the form of the structure.

5.4.13 Constructability

Retain the Bridge Manual requirements for construction methods to be considered in the Design Statement, but extend them to require documentation of an envisaged construction method when this forms the basis of the design.

5.4.14 Utilities

Merge the requirements of the two documents pertaining to utilities, but taking into account Transit New Zealand's legal position in respect to these.

5.5 Design Loadings

5.5.1 Dead Load and Superimposed Dead Load

Adopt the Austroads approach of applying different load factors for steel and concrete weights. Retain the Bridge Manual specification of minimum weight allowance for surfacing. Consider including a minimum weight provision for utilities.

5.5.2 Live Load and Overload

Adoption of the Austroads Code dynamic load allowance is not recommended. Any revision of design traffic load impact factors should include a review of the Ontario Highway Bridge Design Code and supporting references.

Retention of the HN - HO design loading is recommended initially. Austroads Code design traffic loadings differ markedly from those of the Bridge Manual. A detailed study of how well Austroads Code loadings model the New Zealand vehicle stream and legal vehicle weights and configurations should be undertaken should adoption be considered. Such a study should also consider projected future changes to vehicle regulations and any proposals for designated heavy transport routes.

For fatigue design, adoption of a method based on the BS 5400 "single vehicle method" is recommended. (This will require completion of a current Transit New Zealand research project.) A detailed evaluation of the Austroads approach should be undertaken prior to its consideration for adoption as an alternative simplified method.

5.5.3 Braking and Traction Loads

Retain the present Bridge Manual basis, but consider revision of the percentage of live loading applied.

5.5.4 Centrifugal Force

Retain the present Bridge Manual criteria but revise them to include consideration of loaded length producing the worst effect for different elements of the bridge.

5.5.5 Collision Load

Adopt the Austroads Code criteria as an initial basis for further development, but also review other codes, e.g. BS 5400, and develop more comprehensive requirements.

5.5.6 Kerb and Barrier Loads

Detailed study should be undertaken to resolve the significant differences between the Austroads Code and Bridge Manual approaches. (This is being addressed by a joint Australian - New Zealand working party). The possibility of stock applying loading to pedestrian barriers should be catered for.

5.5.7 Footpath and Cycletrack Loadings

Retain the Bridge Manual requirements, but review them to specifically include footbridges and to include provision for stock loading.

5.5.8 Wind Loads

Requirements for the derivation of design wind speed that are consistent with the adopted limit state basis, design lives for the various structures and New Zealand conditions, require development. NZS 4203 provides a basis for this.

Retain the BS 5400 approach adopted by the Bridge Manual for the derivation of wind load on bridges.

Review the Austroads Code and compare it against other codes for adoption for wind load requirements for poles and signs. Develop and include wind load requirements for pedestrian bridges, including those roofed or fully enclosed.

5.5.9 Thermal Effects

Merge the Austroads Code and Bridge Manual requirements for application of temperature load and tailor to New Zealand conditions.

Review and develop design temperature ranges consistent with the adopted limit state basis, range of design lives and New Zealand conditions.

Evaluate the differences in differential temperature design temperature gradient curves to resolve which are appropriate for adoption.

5.5.10 Water Flow Forces

Adopt the Austroads requirements as the basis for further development. Even if inundation is not accepted at the ULS, include provisions for this possibility in an extreme event.

5.5.11 Earth Loads and Effects

Review and merge the Austroads Code and Bridge Manual requirements, converting prescriptive requirements to performance criteria where possible. Expand provisions for earthquake induced effects, and include provisions for the effects of lateral spreading of soil on foundations.

5.5.12 Frictional Forces and Elastomeric Bearing and Deck Joint Forces

Include within the Analysis and Design Criteria section requirements dealing specifically with bearing friction and forces arising from distortion of elastomeric elements. The Austroads Code provides some basis for this. Include requirements for consideration of upper and lower bounds of friction and elastomeric element stiffness. Contrary to the Austroads Code approach, treat these forces as internal responses of the structure to external loads or actions and do not assign load factors to these responses separately to those assigned to the external forces and actions.

5.5.13 Shrinkage Creep and Prestress Effects

Merge the requirements of the Austroads Code and the Bridge Manual. Incorporate requirements for consideration of: the effects of long term creep associated with prestress on bridge deck joint gaps; and the effects of superstructure dead load long term creep deflection in reinforced and prestressed concrete bridges.

Review the need for a requirement to consider upper and lower bounds for these effects.

5.5.14 Construction Loads and Effects

Adopt the Austroads Code requirements, and include a requirement for checking, during construction, the capacity of the structure for the contractor's actual equipment.

5.5.15 Earthquake Loads

Retain the Bridge Manual requirements but review them for consistency with the adopted limit state basis. Encourage debate and research to justify the structural performance factors adopted, and give consideration to including a structural form factor (as in the Austroads Code).

5.5.16 Load Combinations

The Bridge Manual load combinations and load factors require review and revision. Adoption of the Austroads Code load combinations is not recommended without detailed study and modification.

Engage in a comprehensive study to develop appropriate load combinations with a consistent safety index applicable to New Zealand conditions.

5.5.17 Dynamic Behaviour

Review the Austroads requirements with a view to adoption in preference to the Bridge Manual requirements, based on the expectation of their being similarly adequate but simpler to apply.

5.6 Structural Design of Elements

5.6.1 Methods of Analysis and Structural Modelling

This is dealt with primarily in the materials design codes adopted by the Bridge Manual or the Austroads Code materials design sections. Retain this approach in general.

Retain the empirical membrane action approach contained in the Bridge Manual for design of interior deck slab panels.

Retain the Bridge Manual's requirements for structural modelling and analysis for earthquake resistant design.

5.6.2 Main Structural Elements

This is dealt with primarily in the materials design codes adopted by the Bridge Manual or the Austroads Code materials design sections. Retain this approach in general.

Consider presenting all criteria related to the structural design of elements together, in a manner similar to that adopted in NZS 3101, instead of dispersed between Analysis and Design Criteria and Earthquake Resistant Design sections of the Bridge Manual as at present.

5.6.3 Foundations Abutment and Retaining Walls Embankments and Cuttings

Undertake a study to revise the existing Bridge Manual requirements for foundations to include specific criteria for the design of foundation elements and geotechnical structures. Review the present criteria for expression in terms of consistency with the current state-of-the-art and the limit state philosophy. Review the range of available applicable design standards including the Austroads Code. The Austroads Code is not recommended for adoption in its present form without significant modification. Include criteria for ground anchors, extend the existing criteria for retaining walls to provide coverage of the various retaining wall types, and review criteria for earthquake resistant design to provide clearer or more comprehensive coverage of:

- Ground improvement for reduction of liquefaction;
- Selection of appropriate soil stiffness values reflecting limit state pile stiffness degradation; and
- The effects of lateral spreading due to liquefaction.

Retain the present Bridge Manual requirements for embankments and cuttings and extend them to cater specifically for assessment of embankment and cut slope stability, and for mitigation measures for creep and instability of natural ground, in different ground materials.

5.6.4 Culverts and Subways

Adopt the Austroads requirements for culverts and subways as the basis for future development. Extend these to include requirements for the design of corrugated metal plate culverts and arches, and for pipe culverts. Also include requirements for provision for long term serviceability and maintenance.

5.6.5 Bearings

Adopt the Austroads requirements for bearings as the basis for further development subject to undertaking a detailed review of the Austroads Code requirements for elastomeric bearings to identify any significant differences with the Bridge Manual requirements. Review and consider BS 5400:Parts 9.1 and 9.2, and the revised AS 1523 when available, for aspects that should be included.

Include additional requirements for minimum edge distance of bearing plates from the edge of concrete members.

Review the different concrete design codes for requirements for the bearing stress applied to concrete surfaces and consider the need for additional concrete design criteria for the provision and design of confining reinforcement at bearing locations.

5.6.6 Mechanical Energy Dissipating Devices and Load Limiting Devices

Retain the present Bridge Manual requirements for mechanical energy dissipating devices and extend to include requirements for load limiting devices (e.g. abutment knock-off elements). Review other sources of performance criteria (e.g. AASHTO and Caltrans documents).

5.6.7 Deck Joints

Adopt an amalgamation of the generally complementary requirements contained in the Austroads Code and Bridge Manual.

5.6.8 Settlement Slabs Ancillary Items and Date and Loading Panel

Retain the existing Bridge Manual requirements.

5.6.9 Light Poles and Signs

Include performance criteria for the design of lighting poles from Transit New Zealand standard specifications M/18P and M/19. Include referral to Transit New Zealand's "Manual of Traffic Signs and Markings" and "Standard for the Manufacture and Maintenance of Traffic Signs, Posts and Fittings", subject to correction of Appendix B of the latter document.

5.6.10 Snow Avalanche Protection Structures

Review policy toward the provision of avalanche protection, and if adopted, develop criteria for inclusion.

5.7 Materials Design Criteria

5.7.1 Concrete

Retain NZS 3101 Concrete Structure Standard as the basis for concrete design, supplemented by the present additional criteria contained in the Bridge Manual. Undertake a detailed review of the Austroads Code Section 5 to evaluate aspects not so comprehensively covered by NZS 3101, (e.g. the detailing of prestressed concrete anchorage zones and bearing surfaces) and bring to the attention of the Standards New Zealand concrete code committee.

5.7.2 Steel and Composite Design

Retain BS 5400 : Parts 3 and 5 for the present.

Undertake a detailed review of NZS 3404 Steel Structures Standard, on publication of its revision, together with Section 6 of the Australian Bridge Design Code, with a view to adoption of one or other or a combination of both.

5.7.3 Timber

Review NZS 3603:1993 Timber Structures Standard with a view to adoption.

5.7.4 Aluminium and Other Materials

Review BS 8118:1991, and the revised AS 1664 when available, for adoption of one or the other for design in aluminium. Otherwise, retain the existing Bridge Manual requirements.

5.8 Earthquake Resistant Design

Retain the existing Bridge Manual requirements for earthquake resistant design. Review the design seismic hazard spectra for consistency with the adopted limit state basis.
Review the present presentation for appropriateness consistent with the adopted ordering and grouping of criteria and other material into sections.

5.9 Design Criteria for Lightly Trafficked Rural Bridges

Retain the existing Bridge Manual requirements, but review these in the light of the adopted limit state basis and defined services levels that might be adopted.

5.10 Structure Capacity Evaluation

Retain the existing Bridge Manual requirements but revise for consistency with revisions elsewhere in the manual, (e.g. limit state basis, load factors and load combinations).

ABSTRACT

The report presents a definition of the scope and coverage of an ideal manual for the design of roading structures to meet the needs of Transit New Zealand, and compares the present Transit New Zealand Bridge Manual and the '92 Austroads Bridge Design Code with each other and the ideal manual. Recommendations are made on which document to adopt as the basis for future development of a roading structures design manual, and on the adoption and development of criteria for revision of the manual.

1. INTRODUCTION

1.1 General

The Austroads Bridge Design Code is being considered as a base document for a proposed joint Australia/New Zealand Standard. Transit New Zealand commissioned this project to examine its suitability for use in the New Zealand environment, either as a substitute for, or complimentary with the Transit New Zealand Bridge Manual. A critical appraisal of the Australian document has been undertaken to compare its provisions with those of the Bridge Manual, and identify the areas of agreement and disagreement.

A separate issue is that of compliance with the requirements of the New Zealand Building Act 1991. If the Austroads Code were to be used in New Zealand, it would need to be compatible with the requirements of the Act and it would be desirable for it to be referenced by the appropriate Approved Documents published by the Building Industry Authority.

1.2 Project Objectives

Objectives of this study have been to:

- Define in broad terms the coverage required of the "ideal" Transit New Zealand bridge code, as a benchmark against which the existing Austroads Bridge Design Code and Transit New Zealand Bridge Manual can be measured, and as a benchmark for future code development;
- Review the '92 Austroads Bridge Design Code and compare with the Transit New Zealand Bridge Manual. Recommend which of the two documents should be adopted as the base document for future development and upgrade as Transit New Zealand's design code for bridges;
- Identify significant differences between the '92 Austroads Bridge Design Code and the Transit New Zealand Bridge Manual and identify areas requiring revision in the document recommended by the Consultant for acceptance by Transit New Zealand as their base document for the design of bridges; and
- Identify consequential technical issues arising from adopting in whole or in part the '92 Austroads Bridge Design Code for Transit New Zealand policy and administration of the national roading asset.

1.3 Project Context

This project has been undertaken in the context that while initially the code to be adopted will be for application to Transit NZ-funded or -subsidised works, ultimately it may be developed as a New Zealand national standard for the design of bridges.

1.4 Project Overview

The project was undertaken in two stages. Stage 1 encompassed definition of the broad scope of the "Ideal Code" and the range of topics required to be covered within it. The document was seen as fitting within the overall activity of roading structures policy, administration and control, for which a framework was developed, and from that it was resolved that the "Ideal Code" should encompass all structures associated with roading. Consequently the benchmark specification was retitled Ideal Road Structures Design Manual. The framework developed, and the listing of topics requiring coverage in an ideal road structures design manual, are reported in Part A.

Stage 2 encompassed a comparison of the Transit New Zealand Bridge Manual and '92 Austroads Bridge Design Code with each other and the topic listing of the Ideal Road Structures Design Manual. These comparisons are presented in Part B.

Part C presents the conclusions for the whole project.

PART A: DEFINITION OF THE IDEAL DESIGN DOCUMENT

2. FRAMEWORK

2.1 Roading Structures Policy Administration and Control

The following framework sets out the range of documentation associated with roading structures policy, administration and control. These provide the context within which the scope of the ideal bridge design document is to be defined.

Management Principles and Objectives

Organisation

- Allocation of responsibilities;
- Policy;
- Risk;
- Intended life;
- Life cycle costing and replacement;
- Health and safety (e.g. of people, of the structures); and
- Asset usage (e.g. policy on configurations and weights of vehicles to be provided for, policy on carriage of utilities).

Management Process

- Project initiation and evaluation;
- Project development (investigation and design);
- Project construction management and quality control;
- Asset maintenance and rehabilitation; and
- Asset usage control (e.g. overweight permitting, Bridge Posting).

Information System

- Inventory of structures; and
- Individual asset records (site data, as-built records, capacity evaluation, condition).

Design Codes of Practices

- Design objectives, philosophy and basis;
- Requirements specific to structural form, (encompassing scope, geometric requirements, loadings and environmental effects acting on the structure, criteria for health and safety, strength, serviceability, durability, maintainability, aesthetics, analysis and design of structural elements) for:

- Bridges
- Culverts
- Pedestrian bridges
- Pedestrian subways
- Foundations
- Embankments
- Retaining walls
- Geotextile reinforced soil and gabion structures
- Cut slopes
- Traffic and pedestrian barriers
- Signs
- Lighting poles.

- Requirements specific to design in materials (encompassing properties such as reliability, strength and ductility and durability) for:
  - Concrete
  - Steel
  - Timber
  - Aluminium
  - Other materials (fibre reinforced materials, plastics, etc).

Procedures

- Site data gathering and recording;
- Project evaluation;
- Design statement (statement of the design concept for approval in principle);
- Structure inspection and condition evaluation;
- Structure capacity evaluation;
- Bridge overload permitting; and
- Bridge posting (instigation and notification of loading restriction).

Guidelines

- Means of compliance with design codes of practice requirements (e.g. guardrail design);
- Design guidelines (e.g. waterway design);
- Structure inspection and condition evaluation; and
- Structure maintenance and rehabilitation.

Specifications for Manufacture and Construction

2.2 Discussion

Ultimately, it is considered that Transit New Zealand need to have documents which cater for all the items outlined in the framework above. It is suggested that this could be arranged as a series of volumes as follows:

Volume 1

- Management Principles & Objectives
- Policy
- Management Processes
- Information System - policy and organisation.

Volume 2

- Road Structures Design Manual - incorporating all aspects listed above under Design Codes of Practice, and other aspects relevant to the design process e.g. site data gathering and recording, and design statement, listed under Procedures, and means of compliance, listed under Guidelines. Evaluation of structural capacity should also be included as an analysis activity closely aligned to design.

Volume 3

- Specifications for Manufacture and Construction

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- Procedures and Guidelines - individual volumes, each providing procedures or guidelines on a particular topic area e.g. **Procedures**: project evaluation; structure inspection and condition evaluation; and structure overload permitting and **Guidelines:** waterway design; structure inspection, condition evaluation; and maintenance and rehabilitation.

The existing Transit New Zealand Bridge Manual is broader in its scope than the '92 Austroads Bridge Design Code. It is considered desirable that this project encompass at least the breadth of scope encompassed by the Transit New Zealand Bridge Manual to ensure that the existing coverage outside the more narrow scope of a purely bridge design code does not get discarded and lost.

2.2.1 Other codes

A brief review of other bridge codes reveals a variety of ranges of scope.

The British BS 5400 is strictly a bridge design code, covering bridges only and with no coverage of foundations or walls, or of capacity evaluation.

The Ontario Highway Bridge Design Code includes design of retaining walls, soil-steel structures (plate culverts), and evaluation of existing structures.

The AASHTO (American Association of State Highway Officials) codes are intended for the design, evaluation and rehabilitation of bridges and includes foundations, walls, buried structures (e.g. various culvert forms) and tunnel liners.

The '92 Austroads Bridge Design Code defines its scope as including the design of structures designed to support traffic loads, and includes retaining walls, but does not include evaluation of existing structures. Advice received from Standards New Zealand indicates that publication of a Section 7: Rating is planned for this year.

A general feature of these foreign codes is that they all contain materials design requirements. This practice may reflect the separation that commonly exists in those countries between engineers practicing in civil engineering (including roading structures) and those practicing in structural engineering for buildings. New Zealand structural engineers tend to practice more generally in both civil engineering structures and structural engineering for buildings. For New Zealand circumstances it is considered more appropriate to adopt national loadings and materials design standards where state-of-the-art standards are available and with which designers tend to be very familiar.

2.3 Adopted Scope

The scope adopted for study in this project was agreed with Transit New Zealand to be that of a road structures design manual as outlined in the Discussion section above.

3. TOPICS REQUIRING COVERAGE

3.1 Introduction

The following sections set out a listing of topics requiring coverage in an ideal road structures design manual meeting the needs of Transit New Zealand. The sections and topics have been grouped into six broad areas:

- General.
- General Design Criteria.
- Design Loadings.
- Analysis and Design Criteria.
- Means of Compliance.
- Structure Capacity Evaluation.

3.2 General

Code Applicability and Scope

- Structures to which the code is applicable (highway bridges, culverts of >3.0m^2 cross-sectional area, subways and footbridges, retaining walls, embankments, traffic barriers, lighting poles and signs and snow avalanche protection structures).
- Authorities and facility operators to which the code is applied.
- Status of the code under the New Zealand Building Act.
- Code scope.

Design Objectives Philosophy and Basis

- Fitness for purpose (economic, aesthetic, safe, environmental impact etc).
- Designs to be based on scientific theory and a probabilistic approach.
- Design life:
  - for principal structures;
  - for ancillary elements.
- Limit states:
  - ultimate and structural integrity;
  - serviceability.
- Methods of design analysis.

Project Initiation and Approval

- Scheme assessment.
- Design statement:
  - content;
  - acceptance / approval.

Site Information

- Requirements and recording of site information;
- Site investigations.

3.3 General Design Criteria

Geometric Requirements

- Carriageway widths.
- Cycle way widths, footpath widths and edge clearance.
- Vertical clearances from underlying roadway, railway, cycle and pedestrian ways.
- Horizontal clearance of substructure from underlying roadway and railway.
- Superelevation, crossfall, and geometric requirements for deck drainage.
- Pedestrian bridges:
  - width between side barriers;
  - ramp and stair gradients and geometry;
  - geometry and spacing of landings.
- Pedestrian subways:
  - clear width and height;
  - ramp and stair gradients and geometry;
  - geometry and spacing of landings;
  - geometric requirements for drainage and visibility (safety).

Waterway

- Resource Consent:
  - environmental impact (navigation clearances, adjacent land usage impact, effects on channel bed and banks and wildlife habitat, etc).
- River / stream channel stability:
  - natural characteristics of the channel; changes in the characteristics of the channel arising from natural processes and the proposed works.
- Structure service level requirements:
  - under design magnitude flood;
  - under floods of greater than design magnitude.

- Bridge minimum clearance, navigation clearances and waterway capacity requirements.
- Culvert minimum clearance, maximum heading up and capacity requirements.
- Optimisation of waterway opening and bridge length.
- Flood estimation basis and methods.
- Provision for debris.
- Stability of abutments and approach embankments (scour, piping, protection works, river training works etc).
- Scour design considerations and requirements.
- Visibility of flooded roadway.

Hazards Inherent in the Site

- General principles:
  - consideration of potential hazards e.g. fire; rock or snow avalanche; mass ground movement; or soil liquefaction in earthquake.

Traffic Safety

- General principles:
  - safety of the structure;
  - safety of users.

Traffic Barriers

- Performance criteria:
  - barrier properties such as vehicle containment, energy absorption, strength, repairability, compatibility with structure and vision obstruction;
  - service levels relative to site conditions.
- Means of compliance:
  - acceptable solutions including guidelines on geometric layout;
  - compliance demonstration by testing.

Pedestrian Barriers

- Performance criteria:
  - barrier properties such as people containment, strength, safety, maintenance, compatability with structure and vision obstruction;
  - service levels relative to site conditions.

Wind and Noise Shielding Barriers

- Criteria for their provision.
- Performance criteria.

Lighting

- Criteria for lighting provision:
  - road bridges;
  - pedestrian bridges;
  - pedestrian subways.
- Performance criteria:
  - illumination of the structure;
  - illumination of trafficked surfaces;
  - user safety;
  - serviceability of lighting fittings and supports.

Trafficked Surfaces (vehicle and pedestrian)

- Wearing surface:
  - surface texture (anti-skid, noise);
  - wearability;
  - compatibility with surfacing on approaches;
  - icing mitigation;
- Rideability:
  - deck joints;
  - approach transition and settlement slabs.

Drainage

- Provision against water ponding, and control of water flow.
- Water discharge.
- Maintenance and durability of drainage systems.
- Structure detailing:
  - durability against drainage-induced deterioration;
  - against water entrapment.

Durability

- Use of materials:
  - selection of materials;
  - protection against corrosion or damage.

- Structure detailing:
  - protection or replacement of, components susceptible to damage.

Structure Aesthetics

- Concepts and considerations:
  - principles (form, proportion, harmony, scale, expression of function and stability, texture, colour, light and shade, illusion, rhyme and rhythm.
- Long term appearance.

Deformations

- General principles.
- Deflection limit criteria.

Access for Inspection and Maintenance

- Access level relative to structure form, element, site conditions, etc.

Constructability

- Envisaged construction method.
- Design detailing for constructability.
- Environmental considerations (e.g. rainfall and flood risk).
- Built-in forces and effects arising from construction method.

Economy

- Evaluation of structural form and materials options based on whole-of-life costs.

Utilities

- Utilities to be provided.
- Conditions applying:
  - methods of attachment;
  - modifications to the structure;
  - maintenance of the utility and fixings;
  - liability and indemnity requirements..
- Provision for breakage and leakage.

3.4 Design Loadings

Dead Loads

- Dead load:
  - definition;
  - basis of assessment.
- Superimposed dead load:
  - definition;
  - basis of assessment.
- Limit state load factors.

Traffic Loads

- Normal design load:
  - lane load;
  - vehicle axle loads, spacing and configuration;
  - wheel load and contact area.
- Abnormal loading:
  - lane load;
  - vehicle axle loads, spacing and configuration;
  - wheel load and contact area.
- Fatigue loading:
  - design vehicle loading and configuration;
  - loading spectrum relative to service conditions.
- Dynamic amplification:
  - normal design loading;
  - abnormal loading;
  - application to elements of the structure.
- Application of loadings:
  - positioning on carriageway;
  - concurrency of multiple loadings;
  - on footpaths, cycleways and kerbs;
  - application on buried structures (culverts and subways).
- Centrifugal forces.
- Braking and traction forces.
- Limit state load factors.

Pedestrian Cyclist and Stock Loads

- Design pedestrian load:
  - magnitude and variation with loaded area.
- Design stock loading:
  - magnitude and variation with loaded area;
  - dynamic amplification.

- Application of loadings:
  - concurrency with traffic loading.
- Design loading on barriers:
  - magnitude and variation with service level;
  - application to barriers.
- Limit state load factors.

Loading from Other Transport Modes

Derive loadings due to other transport modes (e.g. trains, light rail, trams) for dual or multiple purpose structures.

Collision Loads

- Design collision loads from road traffic.
- Design collision loads from rail traffic.
- Application of loadings:
  - to piers;
  - provision of clearance from carriage-way or side protection to nullify need for design collision loading;
  - to superstructures.
- Limit state load factors.
- Provision for marine craft impact on piers.

Kerb and Barrier Loadings

- Traffic barrier and kerb loading:
  - magnitude and variation with service level.
- Pedestrian barrier loading:
  - magnitude and variation with service level.
- Stock barrier loading:
  - magnitude.
- Application of loading to the barrier.
- Limit state load factors.

Wind Load

- Design wind speed:
  - limit state (return period);
  - structure importance.

- Transverse wind load:
  - effective area;
  - drag coefficients.
- Longitudinal wind load:
  - effective area;
  - drag coefficients.
- Vertical wind load:
  - effective area;
  - lift coefficient.
- Aeroelastic instability.
- Signs and light poles:
  - wind load;
  - vibration.

Thermal Effects

- Variation in average temperature.
- Differential temperature gradients.
- Limit state (return period).

Water Flow Forces

- Design flow and pressure:
  - limit state (return period);
  - structure importance.
- Forces on piers:
  - effective area;
  - drag coefficient;
  - lift coefficient.
- Forces due to debris:
  - effective area;
  - drag coefficient.
- Forces due to log impact.
- Detailing for greater than design event:
  - superstructure buoyancy.

Earth Loads and Effects

- Static earth pressure.
- Earthquake earth pressure.
- Water pressure and drainage.
- Compaction pressure.
- Live load surcharge.
- Settlement and differential settlement.
- Negative skin friction on piles.
- Liquefaction under earthquake vibration.
- Treatment of earth pressures providing structural benefit.
- Limit state load factors.

Frictional and Elastomeric Forces

- Frictional restraint from bearings.
- Elastomeric bearing forces due to displacement.
- Forces arising from expansion joints.
- Upper and lower bound treatment of frictional restraint and elastomeric element forces.
- Limit state load factors.

Earthquake Loads

- Design loading (horizontal and vertical):
  - hazard spectra corresponding to site sub-soil type and regional and site seismicity;
  - structure importance;
  - structure ductility;
  - structure performance;
  - structure type (bridge, earth retaining, etc);
  - concurrency of earthquake actions on different axes;
  - limit state (return period).

Shrinkage Creep and Prestress Effects

- Consideration of shrinkage, creep and prestress effects.
- Consideration of upper and lower bound of effects.
- Dead load balance / long term creep deflection profile.
- Limit state load factors.

Construction Loads and Effects

- Consideration of construction loads and effects, and associated risk.
- Consideration of method and sequence of construction.
- Consideration of handling stresses: falsework stiffness; settlement and capacity; and loads from permanent works on falsework.

Load Combinations

- Load combinations:
  - limit state;
  - directional combinations.

Dynamic Behaviour

• Road bridges:	- presence or absence of footpaths.
• Pedestrian bridges.	
• Bridges generally:	- perceptible and disturbing vibrations of no structural strength significance.
• Pole supported structures:	- wind vibration.

3.5 Analysis and Design Criteria

Analysis

• Modelling of elements:	- effect of concrete cracking on stiffness. - support flexural and torsional rigidity. - membrane action in deck slabs.

Materials Design Criteria

Materials covered are: reinforced and prestressed concrete; steel; timber and aluminium.

• Design criteria to be applied to each material are:	- limit state design requirements and material properties; - principles and requirements for analysis and design; - durability; - flexural strength (with and without axial load), shear and torsion strength, and stability; - fatigue; - composite construction; - design and detailing of structural elements; - design and detailing of joints and connections; - design and detailing for ductility and post-elastic behaviour.

Design Criteria for Elements

• Foundations:	- geotechnical categorisation (size and type of construction; risk to adjacent property; and ground conditions e.g. soil type, groundwater and seismicity);

- site investigations;
- considerations and limit state requirements for shallow and deep foundations and anchors;
- earthquake considerations (including liquefaction potential and mitigation, effects of lateral spreading and assessment of foundation stiffness and stiffness degradation).

- Earth retaining structures:
  - design life and durability;
  - design considerations and limit state requirements for wall forms (gravity and counterfort, cantilever and soldier pile, tied back, crib, mechanically stabilised, gabion and sheet pile walls.
- Integral and semi-integral abutments.
- Embankments:
  - design considerations (including foundation strength and settlement; embankment materials and compaction; slope stability; and stabilisation by reinforcement).
- Cuttings:
  - design considerations (including: slope stability and surface slumping; rock protection and rock fall control; and rock bolting).
- Culverts and subways:
  - rigid structures;
  - flexible structures (e.g. corrugated plate metal culverts).
- Bearings:
  - general criteria (design life, limit states, inspection and maintenance, replace-ability, positioning, attachment, stability, forces arising from resistance to movement, etc).
  - Additional criteria for the design of specific bearing types (rocker and roller type, knuckle and leaf type, elastomeric type etc).
- Mechanical energy dissipation devices and load limiting devices:
  - general criteria (design life, limit states, inspection and maintenance, replaceability and repairability, positioning, attachment, stability, forces arising from resistance to movement, proven mechanical performance etc).

- Deck joints:
  - general criteria (limit states, design loads, installation and attachment, water-lightness, replaceability, etc).
- Settlement and friction slabs:
  - general criteria (design life, limit states, attachment, frictional resistance, etc).
- Side protection:
  - traffic barriers, pedestrian barriers and kerbs.
- Date and loading panel.
- Ancillary items (hold down and linkage bolts, shear keys, etc).
- Lighting poles.
- Sign structures.
- Snow avalanche protection structures.

Earthquake Resistant Design

- Philosophy:
  - performance objectives;
  - structure classification.
- Analysis methods:
  - equivalent static force analysis;
  - dynamic analysis (modal and time history);
  - element properties.
- Analysis modelling of members and member design criteria:
  - ductile structure, partially ductile structure, structure of limited ductility, elastic structure;
  - conditions at locations of support and/or restraint;
  - structure incorporating energy dissipating devices.
- Structural integrity and provision for relative displacements.

Design Criteria for Lightly Trafficked Rural Bridges

- Applicability.
- Specific Requirements:
  - geometrics;
  - side protection;
  - design loadings.

3.6 Means of Compliance

Acceptable Solutions Satisfying the Specified Performance Criteria

- Traffic barriers.
- Safety kerbs.
- Pedestrian barriers.
- Toroidal buffers.

3.7 Structure Capacity Evaluation

Evaluation of Load Carrying Capacity

- Evaluation
  - capacity rating;
  - posting.

Each form of evaluation should include: main members; deck slabs; material of construction and proof load testing.

4. CRITERIA TO BE MET

4.1 Introduction

The ideal manual should satisfy the criteria set out in the following sections in its presentation and content.

4.2 Limit State Format

The manual be expressed in a limit state format. Consistent with national and recognised international codes, two limit states are to be considered:

- Serviceability limit state, which deals with deformation and deflection limits, and durability, which affect the appearance or function of the structure; and
- Ultimate limit state, which relates to the strength and stability of the structure and its parts to withstand the specified loads.

4.3 Performance Based Criteria and Completeness of Specification

The manual be expressed in terms of performance based criteria wherever possible, rather than in terms of prescriptive criteria. Performance based criteria will provide maximum scope for innovation and economy in design to meet the specific conditions and requirements of each project. Verification and certification procedures, to confirm that the performance criteria are satisfied by a design, also need to be incorporated.

Performance based or prescriptive criteria must fully and explicitly prescribe the solution, and not leave aspects to be governed by such phrases as "as approved by the engineer", "in accordance with the manufacturer's instructions", and "shall have regard to seismic effects". This will be necessary if the manual is to be accepted by the Building Industry Authority as including a national bridge code.

4.4 Harmonisation of Design Loadings with Design Life

Design loadings and load combinations are derived on a basis of harmonisation of design life with Transit New Zealand's risk policy with respect to each of the hazards that may affect structures designed in accordance with the manual.

4.5 Consistency of Nomenclature

The manual be expressed in nomenclature consistent with other reference codes and documents, in particular with that used by related New Zealand standards.

4.6 Materials Design Criteria

Where the appropriate state-of-the-art national loadings and materials design standards are available, the manual adopt the national standards as the basis for design for these loadings or in these materials, or incorporate into the manual criteria that are consistent with the national standards. It is preferable to adopt national standards, rather than for the manual to contain criteria consistent with the national standards, for two reasons:

- Minimisation of effort from the New Zealand engineering community to the revision of design standards and acquiring their acceptance by the BIA. Realistically endeavouring to develop and maintain duplicate materials codes in an up-to-date state is likely to strain New Zealand's resource of qualified specialists.
- Practising engineers in New Zealand, engaged in bridge design, will generally also be engaged in the design of other structures to the national standards. Thus, adoption of national standards can be expected to eliminate any confusion that might arise through engineers applying different standards to work of a similar nature.

As necessary, the road structures manual may incorporate additional materials criteria, where not covered by the adopted national materials codes (e.g. bridge deck slab design based on membrane action).

4.7 Building Act Compatibility

The manual be compatible with the New Zealand Building Act, and, with the exception of any disclaimer contained be acceptable to the BIA for referencing by the appropriate Approved Documents for the intended range of application.

(To be resolved by Transit New Zealand is whether the manual be intended to apply as a national bridge code, or as a bridge code limited to Transit New Zealand funded or subsidised works.)

4.8 Means of Compliance

For aspects of performance based design criteria for which compliance may be onerous to demonstrate, the manual provide acceptable "means of compliance" solutions (e.g. traffic barriers).

4.9 Publication Format

The manual be published in a format enabling amendment with minimal effort. To this end, a loose leaf format, as adopted by the present Transit New Zealand "Bridge Manual" is to be preferred.

PART B: COMPARISON OF THE 3 MANUALS

5. CODE STRUCTURE FORMAT AND TOPICS COVERED

5.1 Code Structure and Format

5.1.1 Transit New Zealand Bridge Manual

The Bridge Manual comprises one volume divided into sections entitled:

- Design Statement.
- Design - General Requirements.
- Design Loading.
- Analysis and Design Criteria.
- Earthquake Resistant Design.
- Evaluation of Existing Bridges and Culverts.
- Appendices.

There is no supporting Commentary.

"Design Statement" provides for an agreed basis between the designer and client as to the nature of structure to be designed. It also sets out the pre-design process expected to have preceded the initiation of design and requirements for the Design Statement.

"Design - General Requirements" sets out the design philosophy, and requirements for geometric design and side protection, waterway design, and site investigations, and for consideration of the influence of the approaches.

"Design Loadings" is self explanatory.

"Analysis and Design Criteria" encompasses the material codes to be used, supplemented by any additional requirements; geotechnical aspects; and the design of some particular forms of structures and structural elements.

"Earthquake Resistant Design" covers philosophy, classification of structural behaviour, derivation of design loadings, and criteria for structural analysis and design for New Zealand conditions.

"Evaluation of Existing Bridges and Culverts" sets out criteria for evaluation of the load carrying capacity of these structures. It does not cover evaluation of physical deterioration.

The "Appendices" encompass:

- Bridge widths and clearances;
- Bridge side protection (i.e. traffic and pedestrian barriers and kerbs);
- Toroidal rubber buffers;
- Design criteria for lightly trafficked rural bridges;
- Bridge site information summary;
- References.

The Bridge Manual is presented in a loose leaf ringbinder format, which allows easy revision of sections of the document and incorporation of new material without complete re-publication of the whole manual.

5.1.2 '92 Austroads Bridge Design Code

The Austroads Code comprises a boxed set of 5 volumes with a further corresponding 5 volumes of Commentary. The volumes correspond logically to sections of the Code:

Section One:	General
Section Two:	Design Loads
Section Three:	Foundations
Section Four:	Bearings and Deck Joints
Section Five:	Concrete

Further sections are indicated to be printed at a later date and are not yet available. These are:

Section Six:	Steel
Section Seven:	Temporary Works

Publication of these additional sections may now have been overtaken by the activities of Standards Australia and Standards New Zealand to develop a joint bridge code encompassing both road and rail bridges.

Under the auspices of the joint Australian/NZ Bridge Code committee, there are draft sections encompassing both road and rail bridges now in existence for:

Section Six:	Steel
Section Eight:	Rating

"Section One: General" encompasses general principles (applicability, philosophy, limit states, analysis methods, etc.), waterway and flood design principles, geometric requirements, traffic and pedestrian barriers, drainage, access for maintenance, and utilities.

"Section Three: Foundations" encompasses not only shallow and deep foundations but geotechnical categorisation, site investigations, anchorages, bridge substructure elements, culverts and retaining walls.

The contents of other sections of the Austroads Code are apparent from their titles.

The Austroads Commentary, in some clauses, goes beyond providing explanation and guidance to presenting design recommendations and requirements. These would be more appropriately located in the Code, (e.g. C2.2.3, C2.3.7).

The volumes are A4 size and relatively thin, many with their first third taken up by the Foreword, Acknowledgments etc that are largely repeated from one volume to the next, and a table of contents specific to the volume.

5.1.3 Recommendations for Code Structure and Format

The two documents are different in the nature of their content. The Austroads Code, as a code, presents design criteria and design guidance, but sets out only considerations to be taken into account or is vague in areas where administering authorities may have different policies. The Bridge Manual, by comparison, includes statements of policy and specific design criteria which are derived from that policy, and structural performance criteria. In general, the Bridge Manual endeavours to avoid prescribing design methods or providing design guidance.

In the revision of the Ministry of Works and Development's "Highway Bridge Design Brief" to create Transit New Zealand's Bridge Manual, a policy decision was taken to specify performance criteria wherever possible and to eliminate prescribed design methods and design guidance. An effect of this approach is to minimise liability to Transit New Zealand arising from the design methods adopted by the designer.

To enable the design of roading structures, the designer must have available all the criteria defining the requirements that the structure must meet, both the structural performance criteria and the criteria derived from policy. From a designers perspective, this is most conveniently achieved by these being presented in one document.

Until such time as there is an acceptable national bridge design standard, it is recommended that Transit New Zealand's road structures design document continue to include policy and the design criteria derived therefrom as well as structural design criteria.

A review of the presentation of the Austroads Code, the Bridge Manual, and other documents has led the researcher to prefer the sections and grouping of topics into them generally as given in Part A: Section 3 Ideal Road Structures Design Manual: Topics Requiring Coverage.

Consideration should be given to whether the present grouping of earthquake resistant design aspects into a single section is the most appropriate. For example the philosophy aspects could be grouped with other aspects of design objectives, philosophy and basis; earthquake loadings with other loadings; and earthquake analysis and structure and element earthquake design criteria with other analysis and design criteria. Design criteria for lightly trafficked rural bridges might also undergo some alteration in presentation, dependent on adoption of defined levels of service as a philosophical approach to defining service requirements.

In adopting the present format for the Bridge Manual, the format of the Austroads Code and others was reviewed by Transit New Zealand staff and the researcher. Based on two years use and one major revision, the format adopted is considered to be the most appropriate.

Experience since the Bridge Manual's publication in 1994 has been that the binding system, using a heavy grade of paper, has proved satisfactory in regular design office use. Stiff card separator sheets need to be provided at the front and back to prevent the first and last text pages from sticking to the plastic covered ringbinder covers, and losing the print off the first page from this contact.

With the Austroads Code each section is contained in its own volume which enables individual sections to be revised and republished without requiring republication of the whole Code. Limited amendments, to few pages, are likely to be handled by issue of amendment advice pages with material to be cut and pasted into the volumes. Insertion of such amendments can get overlooked or result in a messy document, and is not an approach favoured by the researcher. Volumes using staples as their method of binding can suffer their central pages becoming detached with regular use.

Continuation with the present Bridge Manual format of a loose leaf ringbinder is recommended. For ease of use, individual volume size should be close to that of the present manual. Placing the Commentary in separate volumes to the Code is appropriate and is the commonly adopted approach. If Transit New Zealand's future Road Structures Manual is to be referenced by the Approved Documents under the Building Act, any Commentary would be more appropriately published as a separate volume, as Commentary is not referenced by the Approved Documents.

Also, a lot of other material contained within the Manual is not relevant to the Building Code Approved Documents and would need to be distinguished from what is relevant in some way. This includes material related to the contractual obligations between various parties, economic considerations, aspects of project management and planning, aspects of roadway and structure geometry, aspects relating to waterway clearances for navigation, driving sightlines, discharges to watercourses requiring Resource Management Act consent, aesthetics and constructability. Separating material relevant to the Building Code Approved Documents should not be done as that would destroy the continuity of the document. Possible ways of distinguishing material relevant to the Building Code Approved Documents, and also to other legislation and regulations, which may be considered are:

- Highlighting the relevant text, e.g. by putting the text into italics;
- By enclosing the text in boxes together with an enclosed footnote referencing the relevant legislation or regulations;
- By use of annotations in a wide margin; or
- By inclusion of a section in the Manual containing a tabulation of the Manual clauses cross referenced to Building Code clauses and other relevant legislation and regulations.

5.2 Topic Coverage

The following table sets out the list of topics recommended for coverage in the Ideal Road Structures Manual and shows which are covered by the Austroads Code and by the Bridge Manual. Topic coverage is indicated by a "x" in the appropriate column of the table, with supplementary comment provided where appropriate.

Table 1. Ideal Road Structures Manual recommended coverage

IDEAL ROAD STRUCTURES MANUAL TOPICS	TRANSIT NEW ZEALAND BRIDGE MANUAL			AUSTROADS BRIDGE DESIGN CODE			SUPPLEMENTARY COMMENT
	Included Directly	Included by Reference	Not Included	Included Directly	Included by Reference	Not Included	
GENERAL							
Code Applicability & Scope	X			X			TNZ BM: Refers only to structures which are applicable, whereas ABDC also includes organisations.
Design Objectives, Philosophy and Basis	X			X			TNZ BM: Limited to discussion of strength and serviceability and design life, compared to more comprehensive coverage in ABDC.
Project Initiation & Approval	X					X	TNZ BM: Pre-design information and Design Statement
Site Investigations	X			X			
GENERAL DESIGN CRITERIA							
Geometric Requirements	X	X		X			TNZ BM: Road carriageway geometrics and clearance only, referral to NZR for rail clearances. ABDC: Road carriageway geometrics and clearances plus geometry for pedestrian bridges, subways and bikeways. Rail not provided for.
Waterway	X			X			TNZ BM tends to be more specific in its requirements while ABDC tends more to present considerations. ABDC embraces the concept of bridge inundation which TNZ BM does not.
Hazards Inherent at the Site	X					X	TNZ BM: limited to brief mention of influence of approaches and to site instability.
Traffic Safety			X			X	
Traffic Barriers	X			X			TNZ BM provides acceptable solutions ABDC provides some guidance on acceptable solutions, but is less clear

Table 1. Ideal Road Structures Manual recommended coverage

IDEAL ROAD STRUCTURES MANUAL TOPICS	TRANSIT NEW ZEALAND BRIDGE MANUAL			AUSTROADS BRIDGE DESIGN CODE			SUPPLEMENTARY COMMENT
	Included Directly	Included by Reference	Not Included	Included Directly	Included by Reference	Not Included	
GENERAL DESIGN CRITERIA							
Pedestrian Barriers	X			X			
Wind & Noise Shielding Barriers			X			X	
Lighting			X			X	ABDC: Only very limited guidance contained in the Austroads publication AP 11.12/88: "Traffic Engineering Practice - Roadway Lighting".
Trafficked Surfaces			X			X	
Drainage	X			X			
Durability		X		X			TNZ BM: As required by materials codes. ABDC: As contained in sections for foundations, bearing and concrete design.
Bridge Aesthetics			X			X	
Deformations	X			X			TNZ BM: Settlements only covered. Concrete code places limits on beam and slab member thickness to control deflection. ABDC: Deflection limits for beams and slabs, consideration of differential settlements.
Access for Inspection and Maintenance			X	X			ABDC: 1.8 minimal statement, 4.4.6 access to bearings and joints.
Constructability	X					X	
Economy	X					X	

Table 1. Ideal Road Structures Manual recommended coverage

IDEAL ROAD STRUCTURES MANUAL TOPICS	TRANSIT NEW ZEALAND BRIDGE MANUAL			AUSTROADS BRIDGE DESIGN CODE			SUPPLEMENTARY COMMENT
	Included Directly	Included by Reference	Not Included	Included Directly	Included by Reference	Not Included	
Utilities	X			X			
DESIGN LOADINGS							
Dead Loads	X			X			
Traffic Loads	X			X			ABDC traffic loads, impact factor and load combinations for traffic load all differ significantly from TNZ BM.
Pedestrian, Cyclist & Stock Loads	X			X			TNZ BM: No provision made for stock loading. ABDC: Stock allowed as a single point load on footpaths, no dynamic load considered.
Loading from Other Means of Transport			X	X			ABDC: Brief general statement in respect to trams and train loadings.
Collision Loads			X	X			
Kerb & Barrier Loadings	X			X			
Wind Load		X		X			TNZ BM: Refers to NZS 4203 for wind speed and BS 5400 for wind load.
Thermal Effects	X			X			
Water Flow Forces	X			X			
Earth Loads & Effects	X			X			
Frictional and Elastomeric Forces	X			X			TNZ BM: Frictional forces covered only, in Earthquake Resistant Design

Table 1. Ideal Road Structures Manual recommended coverage

IDEAL ROAD STRUCTURES MANUAL TOPICS	TRANSIT NEW ZEALAND BRIDGE MANUAL			AUSTROADS BRIDGE DESIGN CODE			SUPPLEMENTARY COMMENT
	Included Directly	Included by Reference	Not Included	Included Directly	Included by Reference	Not Included	
Earthquake Forces	X			X			ABDC does not consider varying levels of ductility and variation in ground conditions but factors the seismic coefficient based on structural form.
Shrinkage, Creep, & Prestress Effects	X			X			
Construction Loads & Effects	X			X			
Load Combinations	X			X			
Dynamic Behaviour	X			X			
ANALYSIS AND DESIGN CRITERIA							
Analysis (modelling)	X	X		X			
Reinforced & Prestressed Concrete Design Criteria	X	X		X			
Steel Design Criteria		X				X	ABDC: Publication of a steel design section is understood to be imminent.
Timber Design Criteria		X				X	
Aluminium Design Criteria		X				X	
Foundations and Anchorages	X			X			
Earth Retaining Structures	X			X			
Integral & Semi-Integral Abutments	X					X	

Table 1. Ideal Road Structures Manual recommended coverage

IDEAL ROAD STRUCTURES MANUAL TOPICS	TRANSIT NEW ZEALAND BRIDGE MANUAL			AUSTROADS BRIDGE DESIGN CODE			SUPPLEMENTARY COMMENT
ANALYSIS AND DESIGN CRITERIA	Included Directly	Included by Reference	Not Included	Included Directly	Included by Reference	Not Included	
Embankments	X					X	
Cuttings	X					X	
Culverts & Subways	X			X			TNZ BM: No provisions for CSP culvert structures. ABDC: For CSP culvert structures AS 2041, AS 2042, & AS 3703 referenced.
Bearings		X		X			
Mechanical Energy Dissipating Devices & Load Limiting Devices	X					X	
Deck Joints	X			X			
Settlement & Friction Slabs	X					X	
Side Protection	X			X			
Date & Loading Panel	X					X	
Ancillary Bridge Items	X					X	
Lighting Poles			X			X	
Sign Structures			X			X	
Snow Avalanche Protection Structures			X			X	

Table 1. Ideal Road Structures Manual recommended coverage

IDEAL ROAD STRUCTURES MANUAL TOPICS	TRANSIT NEW ZEALAND BRIDGE MANUAL			AUSTROADS BRIDGE DESIGN CODE			SUPPLEMENTARY COMMENT
	Included Directly	Included by Reference	Not Included	Included Directly	Included by Reference	Not Included	
Earthquake Resistant Design - Philosophy, Analysis, & Structural Integrity	X			X			
MEANS OF COMPLIANCE							
Acceptable Solutions	X						
STRUCTURAL CAPACITY EVALUATION							
Capacity Evaluation, Rating & Posting	X					X	ABDC: Provisions for proof loading within Concrete section. Section on rating in preparation.

6. PHILOSOPHY, PRINCIPLES AND APPROACH

6.1 Code Applicability (TNZ BM Introduction, Austroads Code Cl. 1.1)

6.1.1 Documents Coverage

The Austroads Code provides for normal road and pedestrian bridges up to 100m in span, and for other structures associated with roads or with supporting road traffic. The Bridge Manual covers a similar range of bridges but, while not explicitly stated, generally limits its applicability to other structures to those directly associated with bridges. Both documents exclude themselves from applying to corrugated metal plate culvert and metal plate arch type structures.

The Austroads Code is designed for the use by its member Authorities and more generally by other Authorities and organisations. The Bridge Manual makes no representation as to what organisations it applies to.

6.1.2 Discussion and Recommendations

Any code adopted should define the organisations to which it is applicable. In the New Zealand context, this is expected to be significant to achieving Building Industry Authority (BIA) acceptance under the Building Act for referencing in its Approved Documents.

Neither document indicates its status under the New Zealand Building Act. This should be incorporated into the document adopted for future development.

6.2 Project Management and Control (TNZ BM Section 1 & Appendix E)

The Bridge Manual requires preparation of a Design Statement, for endorsement by Transit New Zealand. Required coverage of the Design Statement is set out in the Manual. Site Information Summary data sheets included in the document provide a check list of project information required to be collected at the outset of a project, though use of these data sheets is not mandatory. The Austroads Code contains no similar requirements or guidance.

6.3 Design Life and Durability (TNZ BM Cl. 2.1.3 & 4.2, Austroads Code Cl. 1.1.4 & 5.4)

6.3.1 Design Life

A design life of 100 years is adopted by both documents for bridges. For ancillary elements the Austroads Code allows that a shorter design life may be appropriate, and requires replaceability of bridge components not expected to survive that long. The

Bridge Manual allows variation of the design life by controlling authorities if circumstances require it.

6.3.2 Durability

The New Zealand Building Code requires that a structure's materials, components and construction methods be sufficiently durable to ensure that the structure, without reconstruction or major renovation, will satisfy the other functional requirements of the code throughout its life. In its requirements for the design of concrete, the Austroads Code sets requirements to enable structures to withstand the expected wear and deterioration throughout their design life without the need for undue maintenance, a philosophy similar to that of the Building Code. The Austroads Code's Concrete Section durability requirements are directed at a 100 year design life.

The Bridge Manual is not explicit on the degree of structure maintenance acceptable during the design life, nor on the expected condition at the end of it. New Zealand materials design codes adopted by the Bridge Manual are generally based around achieving a design life of 50 years, which does not accord with the design life of 100 years required for bridges in the Bridge Manual. The materials codes do not present any criteria for achieving a design life exceeding 50 years.

6.3.3 Discussion and Recommendations

Specific definition of design life is required for all the forms of structure to be covered by a Road Structures Design Manual, and requires careful consideration. 100 years is not considered to be appropriate to all structures to be covered by the manual, or even necessarily for all bridges. For example, the Bridge Manual currently allows lower earthquake loads for bridges of lesser importance. Implicit in this approach is a shorter design life if the same probabilities of exceedance within the design life apply, or acceptance of a greater level of damage within the defined design life. Design life, therefore, should relate to the significance of the structure and the ease and economy with which it can be replaced. It is suggested that design life could perhaps be defined by a matrix of type of structure or structural element and route classification.

6.4 Design Bases and Philosophy (TNZ BM Introduction & Cl. 2.1, Austroads Code Cl. 1.1)

6.4.1 Performance Criteria

Specification of performance criteria is the approach adopted by both documents. The Bridge Manual states: "Methods have only been specified where they are considered essential to achieving a satisfactory design".

6.4.2 Limit State Philosophy and Scientific Basis

Both documents adopt a limit state basis (i.e. consideration of the ultimate, safety-related, limit state and the serviceability limit state). This is expressed more consistently in the Austroads Code than in the Bridge Manual in a format consistent with that adopted in recently updated New Zealand standards.

The Austroads Code states: "The design shall be based on scientific theories, experimental data and experience, interpreted statistically as far as possible." Limit state events are defined in terms of probability of occurrence as follows:

Limit State	Return Interval of Event	Probability of being exceeded in any 1 year	Probability of being exceeded in 100 years
Serviceability	20 years	0.05	0.99
Ultimate	2000 years	0.0005	0.05

These probabilities are consistent with the probabilities adopted by the NZS 4203 (Loadings Code) for frequency of occurrence of the serviceability event, and for the safety of the structure over its design life.

The extent to which the Austroads Code has managed to relate soundly to its specified design loadings to these probabilities is not known by the researcher.

The Austroads Code applies the concept of service levels to the design of barriers (Cl. 1.5). Though not defined as a service level, the same sort of concept can be found elsewhere in the definition of geometric requirements, (e.g. vertical clearances (Cl. 1.3.4), and edge clearances (Table 1.3.2)) and in the definition of design traffic loadings (Cl. 2.3.4 and Table 2.3.4). A similar concept could also be considered applicable to waterway design and the frequency of inundation by flooding that is acceptable and is embodied in the Austroads "Waterways Design, A Guide to the Hydraulic Design of Bridges, Culverts and Floodways".

The Bridge Manual does not contain any such equivalent definition of limit states. For those loadings adopted from the NZS 4203, (e.g. wind load and earthquake load), a similar probability basis may be implied, but based on a 5% probability in 50 years for the ultimate limit state. It could not be claimed that the Bridge Manual's specification of loadings is based soundly on a consistent probability.

In adopting NZS 3101 for concrete design, the guidance available for durability design is based again on a 50 year design life, which is out of accord with the design life specified in The Bridge Manual. By comparison the Austroads Code's requirements for durability are directly related to a design life of 100 years, as noted above.

6.4.3 Summary and Recommendations

In summary, within the Austroads Code, the expression of design requirements is judged to be as consistent with the design philosophies as currently practical, while major revision is required to the Bridge Manual to achieve a similar level of consistency. However, inclusion of comprehensive materials design sections in the Manual is not supported.

For a Transit New Zealand ideal manual, or ongoing use of the Bridge Manual, a detailed review should be undertaken and the basis for limit state design clearly defined. Aspects that need resolution include:

- The design life for all types of structures covered by the manual, and whether the same design life should be adopted for structures of the same type but of different importance;
- The accepted probability of exceedance of design loadings and events within the life of the structure;
- The levels of serviceability required of structures. Where possible, these should be quantified e.g. in terms of probability of exceedance of service loads (i.e. a damage criteria), probability of temporary loss of service etc; and
- Interpretation of the Building Act durability requirements to provide a clear definition of such terms as "reconstruction", "major renovation" and "functional requirements" as they are to be applied to roading structures.

7. BRIDGE GEOMETRY AND FORM, AND GENERAL ASPECTS

7.1 Structural Clearances (TNZ BM Appendix A, Austroads Code, Cl. 1.3)

7.1.1 Documents Coverage

The Austroads Code defines preferred and minimum vertical clearances to be provided over roadways and includes an allowance for resealing (100mm). It is not specific on the lateral extent over which the vertical clearance is to be provided. The Bridge Manual by comparison provides clearance diagrams for motorways and highways, but omits to specify clearances for other roads (e.g. urban streets, or non-arterial rural roading). The Bridge Manual clearances above carriageways correspond to the Austroads minimum clearances. There has been a recent trend on major projects to require clearances exceeding those set out in the Bridge Manual indicating possible need for revision of the Bridge Manual clearance specification. The Austroads vertical clearances appear potentially appropriate for New Zealand conditions.

Horizontal clearances are included in the Bridge Manual clearance diagrams, while the Austroads Code lists factors to be considered.

7.1.2 Summary and Recommendations

Use of clearance diagrams provides a clear presentation of minimum criteria, and could also portray preferred criteria. Listing factors to be considered is also desirable, to alert designers to consider whether greater clearances should be provided.

A merging and expansion of the provisions contained in each of the documents would be desirable in an ideal manual.

7.2 Structure Cross-Section Geometry (TNZ BM Appendix A, Austroads Code Cl. 1.3, & 1.4)

7.2.1 Bridge Traffic Lanes Cycleways Footpaths and Superelevation and Crossfall

7.2.1.1 Documents Coverage

The Bridge Manual sets out mandatory requirements for widths of carriageway and footpaths, and allowances for side protection making up the bridge cross-section, and provides a figure of standard deck cross-sections.

The Austroads Code does not specify bridge or carriageway widths other than for low trafficked single lane access bridges. Requirements are provided for the setout of kerbs and barriers, and for the edge distance from traffic lanes to barriers. Guidance on principles to be followed is provided, including a recommendation that the whole of the approach carriageway width, including shoulders and auxiliary lanes be carried across bridges.

Footpath widths are defined by both documents, but differ. Austroads sets minimum and preferred widths, while the Bridge Manual defines minimum and maximum widths on standard bridge cross-sections. The Austroads minimum width is 1.5m compared to the minimums of 1.3m reducing to 1.0m behind guardrail posts.

Requirements are provided in the Austroads Code for the geometry of cycleways. These are omitted from the Bridge Manual. Transit New Zealand's adopted document for cycleways is "Guide to Cycle Facilities", National Roads Board Urban Transport Council, 1985. This document provides recommended cycle lane widths for various densities of usage, based on one- or two-way facilities, and with a 500mm clear flat width required on either side.

The Bridge Manual omits any requirements in respect to superelevation and crossfall, whereas rather generalised requirements are given briefly in the Austroads Code.

7.2.1.2 Summary and Recommendations

Assuming lane widths no narrower than are currently used in New Zealand, the Austroads specification would generally result in wider bridges than currently apply in New Zealand with obvious cost implications for Transit New Zealand if adopted.

The specific statement of widths of bridge cross-section elements and the figure of standard bridge cross-sections in the Bridge Manual provides a simple clear presentation of standard requirements and should be retained.

Consideration should be given to the Austroads requirements for set back of barriers and kerbs from the edge of traffic lanes, which in general are more generous than adopted by Transit New Zealand. Austroads geometric requirements for cycleways appear appropriate for New Zealand use and should be reviewed for adoption as the basis for further development.

A more specific definition of cycleway requirements on bridges than is contained in the "Guide to Cycle Facilities" is desirable and should include the relationship between cycleways and kerbs and barriers.

7.2.2 Pedestrian Bridges and Subways

7.2.2.1 Documents Coverage

Requirements are provided in the Austroads Code for the geometry of pedestrian bridges and subways. These are generally omitted from the Bridge Manual and appear not to be specified by other Transit New Zealand documents.

7.2.2.2 Recommendations

Austroads geometric requirements for pedestrian bridges and subways appear appropriate for New Zealand use and should be reviewed for adoption as the basis for further development.

7.3 Waterway Design (TNZ BM Cl. 2.3, Austroads Code Cl. 1.2 and "Waterway Design: A Guide to Hydraulic Design of Bridges, Culverts and Floodways"

7.3.1 Documents Coverage

Waterway design is covered by Austroads in two documents, the " '92 Austroads Bridge Design Code", and in "Waterway Design: A Guide to the Hydraulic Design of Bridges, Culverts and Floodways". The coverage of all three documents compared to the ideal design manual are summarised in the following table.

7.3.2 Discussion and Recommendations

The Austroads Code together with the Waterway Design Guide are significantly more comprehensive than the Bridge Manual. However, the references made in the Austroads documents to the Australian regulatory environment are not appropriate to New Zealand. In addition, many of the design procedures for scour are not used in the researcher's Wellington office and it is suggested that they may be very conservative in gravel bed rivers. It is recommended that the impact of the Austroads design procedures be evaluated and compared with those commonly in use in New Zealand. However, consistent with Transit New Zealand policy, it is not proposed that a Transit New Zealand Road Structures Design Manual should incorporate design guidelines, but should be limited to specifying performance criteria.

The Austroads Code, is considered to provide the better basis for further development, but should not be adopted without development. It provides a more rational approach to river crossing serviceability. While it lists factors to be considered, it lacks the desired specificity. Reference to aspects of the New Zealand regulatory environment would also be desirable.

The Austroads Code allows for inundation of bridges in the design flood. If a consistent approach is adopted to probability of exceedence at the ULS, the design flood will become one with a 2000 year return period, which is dramatically different from the 100 year return period adopted at present. The philosophy and fundamental principles applied to design for flooding should be reviewed. Consideration should be given to aceptance of bridge and approaches inundation under the design ULS flood, and serviceability levels established (perhaps the present 100 year return period event) at which the bridge and approaches are required to be operable and not inundated.

Table 2. Waterway Design Document Summary

Ideal Design Manual	Transit New Zealand Bridge Manual	'92 Austroads Bridge Design Code, Sections 1 and 2 (including Commentaries)	Austroads' Waterway Design: A Guide to the Hydraulic Design of Bridges, Culverts and Floodways
RESOURCE CONSENT • Environmental impact (navigation clearances, adjacent land usage impact, effects on channel bed and banks and wildlife habitat, etc)	Not well covered. Appendix E (Bridge Site Information Summary) contains some guidelines which are somewhat dated. Design Statement (1.3) mentions "environmental constraints" as a significant factor affecting design.	Briefly covered in 1.2.1, 1.2.2, C1.2.1 and C1.2.2. Regulatory framework not relevant to New Zealand.	General environmental principles briefly covered in 4.4. Regulatory framework not relevant to NZ.
RIVER/STREAM CHANNEL STABILITY • Natural characteristics of the channel; • Changes in the characteristics of the channel arising from natural processes and the proposed works.	Covered in check list form in 2.4 of Appendix E. General principles not covered.	Mentioned very briefly in 1.2.5, C1.2.2 and C1.2.5.	General principles covered in 4.2 and 4.3 with references to standard texts.
STRUCTURE SERVICE LEVEL REQUIREMENTS • Under design magnitude flood. • Under floods of greater than design magnitude.	Bridge must be serviceable under design flood (Q_{100}), but requirements not specified for greater design floods.	Limit states specified in 2.10.2. Requirements to be determined in conjunction with "relevant auth-orities". General principles covered in 1.2.1 and C1.2.1.	Methodology given in 2.2.3, 2.2.4 and 2.2.5.
BRIDGE MINIMUM CLEARANCE, NAVIGATION CLEARANCES, AND WATERWAY CAPACITY REQUIREMENTS.	Minimum clearance and capacity specified 2.3(a). Need for navigation clearances covered in check list form in Appendix E.	To be determined in conjunction with "relevant authorities". General principles covered in 1.2.1 and 1.2.3.	Not explicitly specified. General principles covered in Chapters 2, 4 and 5.
CULVERT MINIMUM CLEARANCE/ MAXIMUM HEADING UP AND CAPACITY REQUIREMENTS	Specified in 2.3(b) and (c).	Does not cover culverts, except as secondary structures (1.2.7).	Not explicitly specified. General principles covered in Chapters 2, 4 and 5.

Table 2. Waterway Design Document Summary

Ideal Design Manual	Transit New Zealand Bridge Manual	'92 Austroads Bridge Design Code, Sections 1 and 2 (including Commentaries)	Austroads' Waterway Design: A Guide to the Hydraulic Design of Bridges, Culverts and Floodways
OPTIMISATION OF WATERWAY OPENING / BRIDGE LENGTH.	Implicit in the considerations for the Design Statement, but not explicitly covered.	Not covered.	Reasonably well covered in 5.3.
FLOOD ESTIMATION BASIS AND METHODS	Not covered.	1.2.3 specifies "methods appropriate to the locality".	Covered in Chapter 3, but much is not relevant to New Zealand.
PROVISION FOR DEBRIS.	Minimum clearance requirement (2.3(a)) affected by large debris. Mentioned in Appendix E. Allowance made in design loading (3.3.8(b)).	Listed as design factor (1.2.1(e)), and design principle (1.2.4 and C1.2.4). Also covered in 2.10.5 and 2.10.6 as design loads.	Mentioned as design factor, but could be better covered.
STABILITY OF APPROACH EMBANKMENTS (scour, piping etc)	Not covered.	Covered as general design principle (1.2.1(d)).	General principles covered, with references to standard texts.
PROTECTION WORKS, RIVER TRAINING WORKS	Not covered.	Covered as a design principle (1.2.5).	General principles covered, with references to standard texts.
SCOUR DESIGN CONSIDERATIONS AND REQUIREMENTS	General principles covered in 2.3(e).	Covered as a design principle, (1.2.1(d) and 1.2.6).	Covered in detail in Chapter 6. Many methods differ from those used in WCS Wellington which tend to be based on research work funded by TNZ (e.g. Melville and Sutherland's local scour design method). Some Austroads scour prediction methods may be very conservative in gravel bed rivers.
VISIBILITY OF FLOODED ROADWAY	Covered for culverts only (2.3(c)) as general principle.	Not covered.	Well covered for culverts and floodways.

7.4 Hazards Inherent in a Bridge Site

Inherent hazards are a fundamental consideration in bridge site selection and in the bridge design. Neither document contains much in the way of requirements in this area. The Bridge Manual notes the need to mitigate against instability or creep of natural ground, to provide for possible slope collapse onto the bridge and for soil liquefaction during earthquake, where these situations arise, and to be aware of earthquake fault locations (clauses 4.9.2, 4.9.3, 5.1.1 & 5.4.6). Other hazards such as fire from underlying urban development, and snow avalanche are not included.

7.5 Traffic Safety and Traffic and Pedestrian Barriers (TNZ BM Appendix B, Austroads Code Cl. 1.5 & 1.6)

7.5.1 Documents Coverage

A section dealing generally with the issues of the safety of the structure and the safety of users is lacking in both documents, though inherent in some of the requirements. The Austroads Code defines design collision loads on piers, but there are considered to be shortcomings in the treatment of collision, discussed later. Other aspects of traffic safety related to sight lines and the alignment of kerbs and barriers on and off the bridge receive mention in the Austroads Code (Cl. 1.3.1).

In the Bridge Manual, barriers are fully defined including geometric layout with standard design details provided as a means of compliance.

In the Austroads Code, traffic barriers are categorised by level of service, and considerations listed as the basis for deciding the level of service required, but there is a lack of specificity in the requirements, this being left to the Authority using the Code to define.

7.5.2 Discussion and Recommendations

Inclusion of a statement of the general philosophy and principles to be applied to the safety of users and of the structure is recommended.

The level of service approach for barriers adopted by Austroads is favoured, but specificity in line with Transit New Zealand policy needs to be added. Barriers are an item where performance generally needs to be established either by extensive experimental testing or past experience in use. While not limiting the use of other alternatives, inclusion within the design manual of solutions that comply is considered to be appropriate.

The Bridge Manual and Austroads Code requirements for barriers differ significantly and a detailed study is required to resolve which is most appropriate. A joint Australian - New Zealand working party is understood to be addressing this.

7.6 Wind and Noise Barriers

No requirements for these are contained in either document, or are contained in any other document developed or adopted by Austroads known to the researcher. Transit New Zealand have published draft guidelines: "Management of Road Traffic Noise - State Highway Improvements". This document sets out both policy and design criteria. Consideration of the need for noise and wind barriers has been a feature of some Transit New Zealand projects over recent years, and can be anticipated to feature more in projects in urban areas in the future.

7.7 Lighting

7.7.1 Documents Coverage

The Bridge Manual and the Austroads Code contain no requirements for lighting, either on bridges or of pedestrian bridges and subways, except for wind loading on poles in the Austroads Code.

The Transit New Zealand "State Highway Control Manual" refers to NZS 6701 and also to NAASRA "Guide to Traffic Engineering Practice, Part 12, Roadway Lighting" for installation guidance. These documents provide guidance on lighting design for illumination, the spacing and set-out of poles along the carriageway, and clearance of poles from the carriageway. NZS 6701, together with AS 1158.1, are currently undergoing revision for publication as a joint Australian / New Zealand standard. The "State Highway Control Manual" also requires all light poles to be of the frangible base type and indicates Transit New Zealand Head Office holds a list of approved pole manufacturers and standards. These documents are generally lacking in specific performance criteria for the structural design of the columns and serviceability of the fittings and supports.

Transit New Zealand standard specifications: TNZ M/18P:1990 Specification for Fibreglass Reinforced Plastic Highway Lighting Columns, and TNZ M/19:1994 Specification for Tubular Steel Lighting Column, both provide performance criteria for load capacity and stiffness. M/18P requires performance testing of a sample of poles supplied for a contract. M/18P covers a flange mounted base fixing only, while M/19 includes requirements for a ground planted type, a flange mounted type, and a frangible base type.

7.7.2 Recommendations

For an ideal Road Structures Design Manual, criteria would need to be developed for lighting provision and its design, on pedestrian bridges and in pedestrian subways. The adequacy of existing requirements for road carriageway lighting in catering for lighting for pedestrians on road bridge footpaths should also be reviewed. Reference to the abovementioned documents would appear to provide design criteria for illumination of bridge carriageways and performance based criteria for the structural design of lighting support structures. The joint Australian / New Zealand standard should be reviewed following its publication for its coverage of the above aspects, with a view to adoption. As a consequence, Transit New Zealand's "State Highway Control Manual" and standard specifications M/18P:1990 and M/19:1994 should also be reviewed and revised as necessary.

7.8 Trafficked Surfaces

7.8.1 Documents Coverage

Neither the Bridge Manual, nor the Austroads Code contain any requirements related to bridge trafficked surfaces (vehicular or pedestrian), other than by the Austroads Code to deck joints (Cl. 4.14), discussed later, and to concrete wearing surfaces concrete strength (Cl.5.4.7), and the Bridge Manual to settlement slabs (Cl.4.11.3).

7.8.2 Recommendations

For an ideal Transit New Zealand Road Structures Design Manual consideration should be given to developing and including criteria pertaining to surface texture and wearability, surfacing compatibility with approaches, and icing mitigation.

7.9 Drainage (TNZ BM Cl. 4.11.4, Austroads Code Cl. 1.7)

7.9.1 Documents Coverage

Both the Bridge Manual and the Austroads Code contain requirements for drainage. These have some commonality, but also requirements worthy of inclusion that do not overlap.

7.9.2 Recommendations

A merging of the requirements of both documents would result in a more comprehensive specification of this topic. In addition, implications of the application of the Resource Management Act to discharging water off bridge decks into water courses needs to be considered and provisions included. More specificity is required in respect to the design of drainage systems (e.g. in respect to the rainfall to be catered for) the provision of cleanouts and inspection/flushing ports, and to the maintenance and replaceability of the system.

7.10 Durability and Economy

7.10.1 Documents Coverage

The Bridge Manual requires selection of the structural solution based on appropriateness and providing the best value for money taking account of both construction and maintenance costs (Cl. 1.3). To some extent this requirement is inconsistent with the Building Act requirement that within a structure's design life reconstruction and major renovation be avoided, and that elements require no more than normal maintenance, to ensure the structure will satisfy its functional requirements. However, within the Building Act, there are no guidelines defining what is major maintenance as distinct from normal maintenance. Bearings are required to be replaceable (Cl. 4.11.1). Concrete durability is addressed by NZS 3101 as has been discussed in 6.4.2 above.

The Austroads Code tends to be more detailed in requirements relating to durability but makes no mention of consideration of the relative whole-of-life costs associated with different alternatives. Generally elements are required to have the same design life as that of the structure overall. Where elements are likely to have a shorter design life, as shown by experience, they are to be replaceable with reusable fixings (Cl. 1.1.4). Specific requirements are given for bearings and deck joints (Cl 4.4). Concrete durability is specified based on a 100 year design life.

7.10.2 Recommendations

Durability is generally addressed better by the Austroads Code, and in a manner more in keeping with the requirements of the Building Act. Whole-of-life cost considerations should be retained but made subordinate to satisfying the Building Code requirements.

7.11 Bridge Aesthetics

Neither the Bridge Manual nor the Austroads Code contain requirements relating to bridge aesthetics. As bridges are expected to survive for 100 years or more, some emphasis on their appearance is considered to be warranted, particularly if they are in an urban environment or are prominent.

7.12 Deformations

7.12.1 Documents Coverage

The Bridge Manual contains requirements to consider vibration and settlements of either the structure or approach fill (Cl. 3.3.12 & 3.3.13). Minimum thickness and depth requirements pertaining to bridges, aimed at controlling deflection and traffic-induced vibration, are to be found in NZS 3101, the adopted concrete materials design code (Cl. 3.3.2.2).

The Austroads Code likewise addresses vibration and settlement (Cl. 2.18 & 2.15). The Austroads requirements for road bridge vibration due to traffic appear easier to use as a design office method than the Bridge Manual approach, but may not be more appropriate.

7.12.2 Discussion and Recommendations

A review of the requirements of each document is recommended to determine which are the more appropriate.

Deck deflection arising from dead load and long term creep in concrete structures is not dealt with by either document. This is believed to have been the source of surface rideability and deck drainage problems on a number of older bridges. Specific criteria need to be developed and included to counter this problem.

A statement of the general principles applying to consideration of deformations should also be included (appearance, rideability, cracking, redistribution of forces, etc).

7.13 Design for Access and Maintenance

7.13.1 Documents Coverage

Requirements for access and maintenance are absent from the Bridge Manual, except for a requirement for bearings to be replaceable (Cl. 4.1.1). The Austroads Code contains a brief general statement (Cl. 1.8), extended in respect to bearings and deck joints with requirements for replaceability of bearings, resetting of bearings and joints and for access. Some elaboration is provided by the Austroads Code Commentary

7.13.2 Recommendations

The Austroads Code provides the better basis for future development. Other aspects that need consideration and possible inclusion are: access to and maintainability of shear keys; drainage systems; services, and into voids (e.g. box girder cells) including minimum access space requirements; and security of access routes from unauthorised users. Consideration should also be given to the need for requirements relating to the form of the structure and the site conditions.

7.14 Constructability

In the Bridge Manual, construction methods are an issue to be considered in preparation of the Design Statement (Cl. 1.3). Neither document explicitly requires constructability to be considered or set down. While the construction method may be the general prerogative of the contractor, a viable construction method, on which the construction detailing is based, must exist and should be recorded. Consideration should also be given to risks associated with environmental conditions.

7.15 Provision for Utilities (TNZ BM Cl. 4.11.5, Austroads Code Cl. 1.9)

7.15.1 Documents Coverage

Requirements are included in the Bridge Manual for utilities from a perspective of consultation with utility operators; advice to them of bridge movements to be accommodated by their services; and consideration of possible consequences arising from the presence of the services on the bridge. Transit New Zealand's legal position, policy and procedures in respect to the carriage of services on bridges, is set out in the "State Highway Control Manual".

Provisions included in the Austroads Code for utilities, are primarily from a perspective of defining the respective responsibilities of the bridge and utility operators.

7.15.2 Recommendations

A merging of the requirements of the two documents would be appropriate, but taking into account Transit New Zealand's legal position.

8. DESIGN LOADINGS

8.1 Dead Load and Superimposed Dead Load

8.1.1 Documents Coverage

Dead load requirements in the two documents are similar, except that the Austroads Code requires consideration of a range of densities when information is not available for an accurate assessment.

Superimposed dead load is similarly specified, except that the Bridge Manual specifies a weight allowance to be made for surfacing regardless of whether the bridge is to be surfaced immediately or not.

In the application of limit state load factors, the Austroads Code applies a lower range of load factors, 1.1 to steel elements, 1.2 to concrete elements, and 2.0 to superimposed dead loads. The Bridge Manual does not differentiate and applies 1.35 to all. An examination of the effect of these various load factors on a range of Works Consultancy Services standard design concrete bridge superstructures for spans up to 26m and for the standard M1 cross-section, indicates that the Transit New Zealand load factor generally results in a slightly higher overall Ultimate Limit State (ULS) dead load than does the Austroads load factors when applied to the separate dead load and superimposed dead load components.

8.1.2 Discussion and Recommendations

The Austroads approach, in applying different load factors to the weight of concrete and steel elements, is more in line with modern overseas codes (e.g. BS 5400), and is more logical, reflecting the different degrees of certainty of those element weights. This approach should be adopted. Specification of a minimum weight allowance for surfacing should be retained. Consideration should be given to including a minimum provision for utilities.

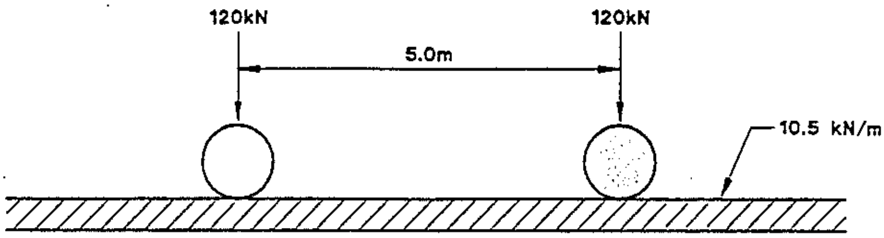
8.2 Live Load and Overload

8.2.1 Gross Loads

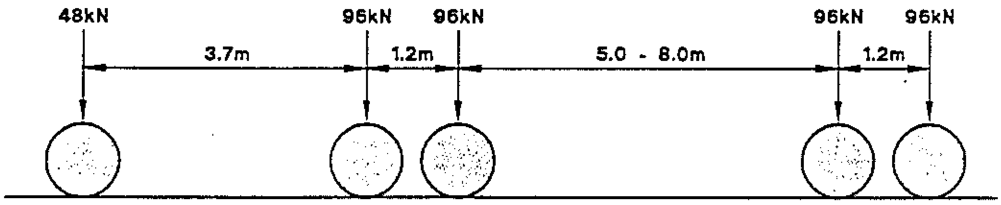
8.2.1.1 Comparisons

The design traffic live loadings differ quite significantly between the Bridge Manual and the Austroads Code.

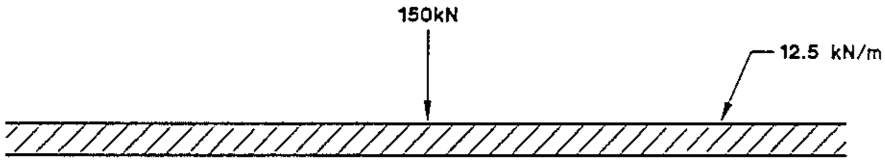
The various loadings are illustrated diagrammatically in Figure 1. For the normal loadings, both the Bridge Manual and Austroads Code loads are applied to a standard lane width of 3.0m. For the overload case, the Bridge Manual HO loading may be applied in one lane concurrently with HN loading occupying other lanes. The Austroads Code Heavy Load Platforms are 3.6m wide for the HLP 320, and 4.5m wide for the HLP 400, and are applied with no other live loading acting concurrently on the bridge.



BRIDGE MANUAL : HN LOADING

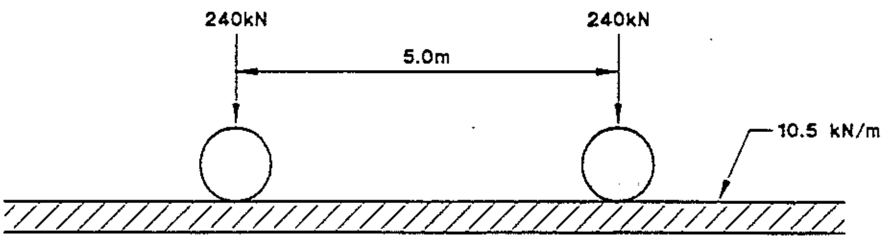


AUSTROADS CODE : T44 LOADING

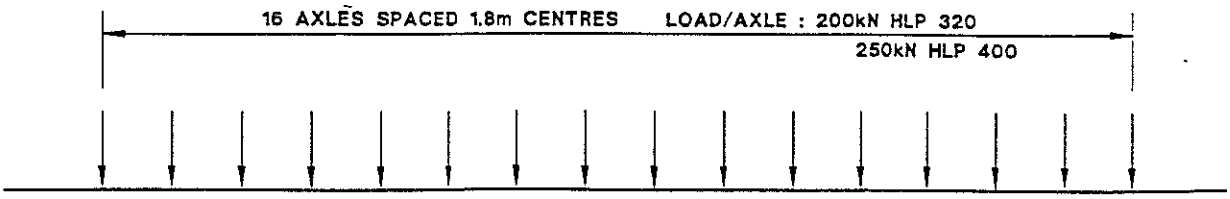


AUSTROADS CODE : T44 LOADING, SPANS > 10m

NORMAL LOADINGS



BRIDGE MANUAL : HO LOADING



AUSTROADS CODE : HEAVY LOAD PLATFORM

OVERLOADS

Figure 1 : Traffic live loadings.

Figures 2 and 3 illustrate the differences in impact factor / dynamic load allowance, and modification for number of lanes loaded. Figures 4 to 7 graph the ULS and unfactored bending moments and reactions for the loads for spans up to 70m, for comparison. At ULS the Transit New Zealand overload case HN-HO is not plotted as it is generally less critical than the normal loading HN-HN.

Within the unfactored load in Figure 5, the Bridge Manual HN loading seems fairly comparable to the Austroads Code T44 / L44 loading for design for moment, though there is greater divergence when considering shear force and reaction plotted in Figure 7.

There is considerable difference in the factors applied to derive ultimate limit state loadings, in all of:

- Impact factor / dynamic load allowance
- Modification factor for number of lanes loaded
- Load factor.

This results in more marked variation between the Bridge Manual and Austroads Code normal loadings at the ultimate limit state.

Dynamic load allowance, in the Austroads Code, is a function of the structure's fundamental period of vertical vibration, and so can only be estimated at the outset of design, for which suggested values are provided in the Commentary.

Design or assessed capacity for live load is a function of the total combination of both dead load and live load acting on the bridge. As indicated above, the ULS dead loads derived by the two documents is almost the same. Therefore the differences in design ULS live load for the same span is fairly representative of the difference in demand on the structures as a whole.

Considering gravity loads only, the ULS load cases are:

Normal Loading

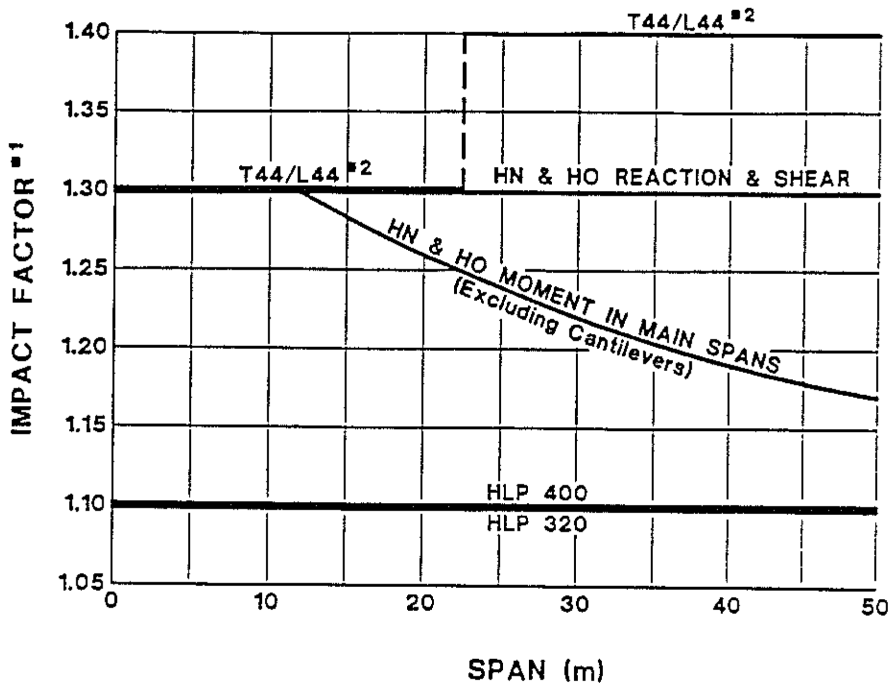
TNZ BM:	U = 1.35DL + 1.35SDL + 2.25LL x LMF x I
Austroads:	U = k.DL + 2.0SDL + 2.0LL x LMF x (1 + DLA)

Overload

TNZ BM:	U = 1.35DL + 1.35SDL + 1.48OL x LMF x I
Austroads:	U = k.DL + 2.0SDL + 1.5OL x (1 + DLA)

Where:

k = 1.20 for concrete, 1.10 for steel in Austroads load cases
I = impact factor
DLA = dynamic load allowance
LMF = modification factor for number of lanes loaded



* Notes :

1. Austroads Code dynamic load allowance (DLA) has been expressed as an equivalent impact factor derived from I = 1 + DLA

2. Dynamic load allowance for T44 and L44 loads is dependent on the structure's fundamental frequency of vibration. The graphed relationship is that proposed by the Austroads Code Commentary Cl. C2.4.2 for use in preliminary design

Figure 2 : Comparison of Bridge Manual impact factor with Austroads Code dynamic load allowance.

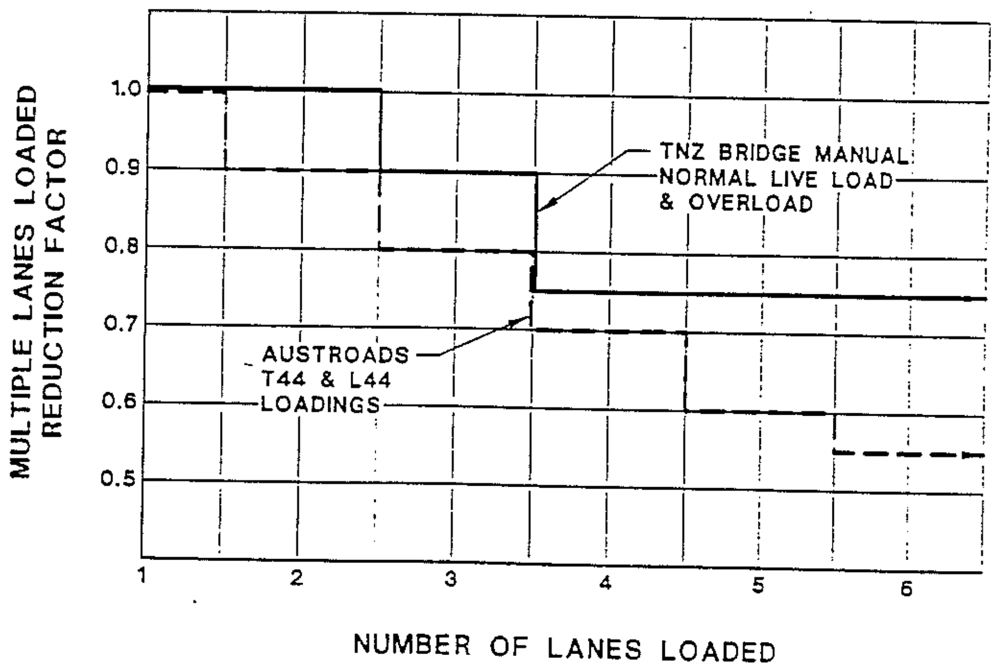


Figure 3 : Comparison of Bridge Manual and Austroads Code reduction factors for multiple lanes loaded.

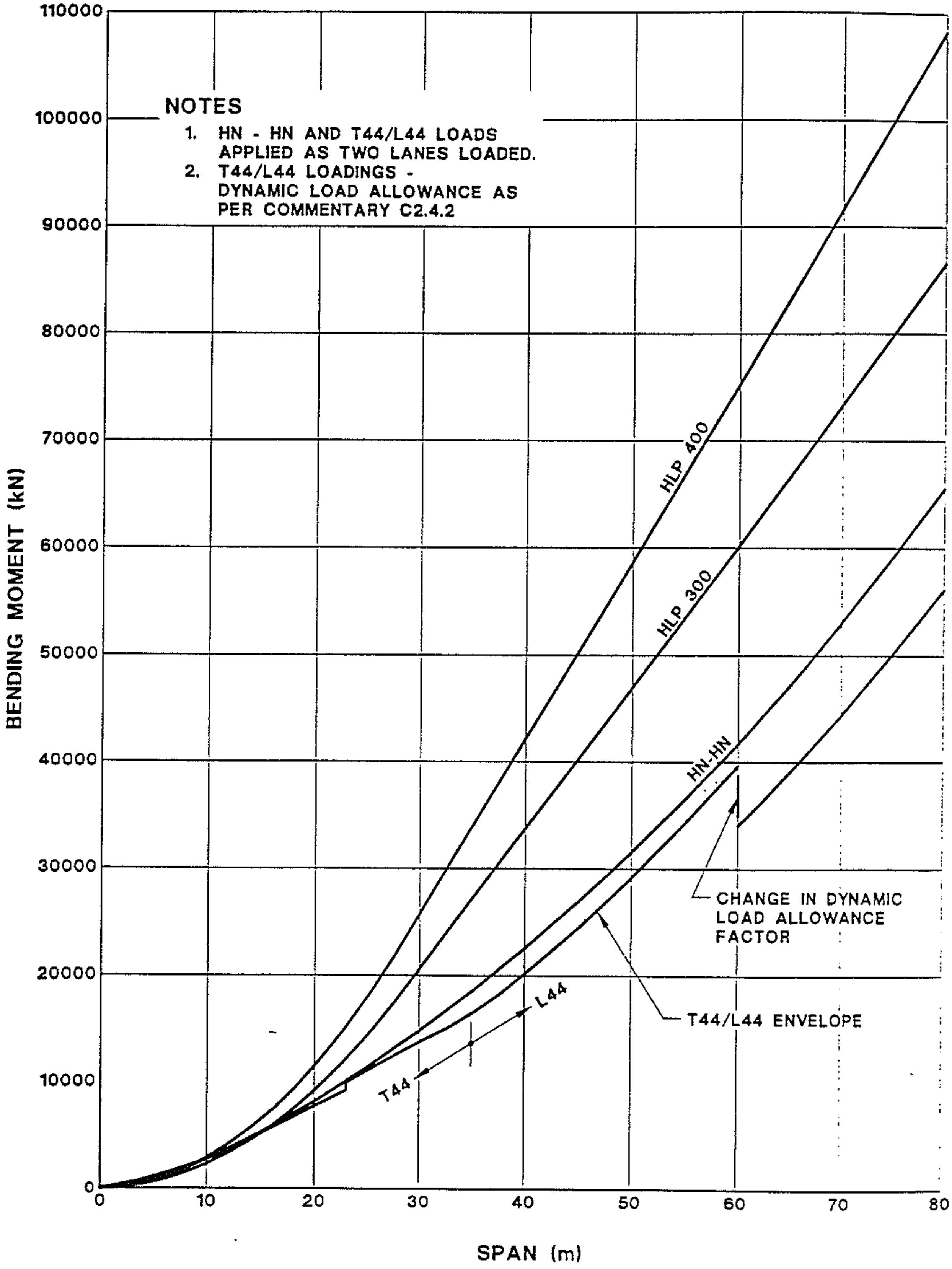


Figure 4 : Ultimate limit state live load bending moments.

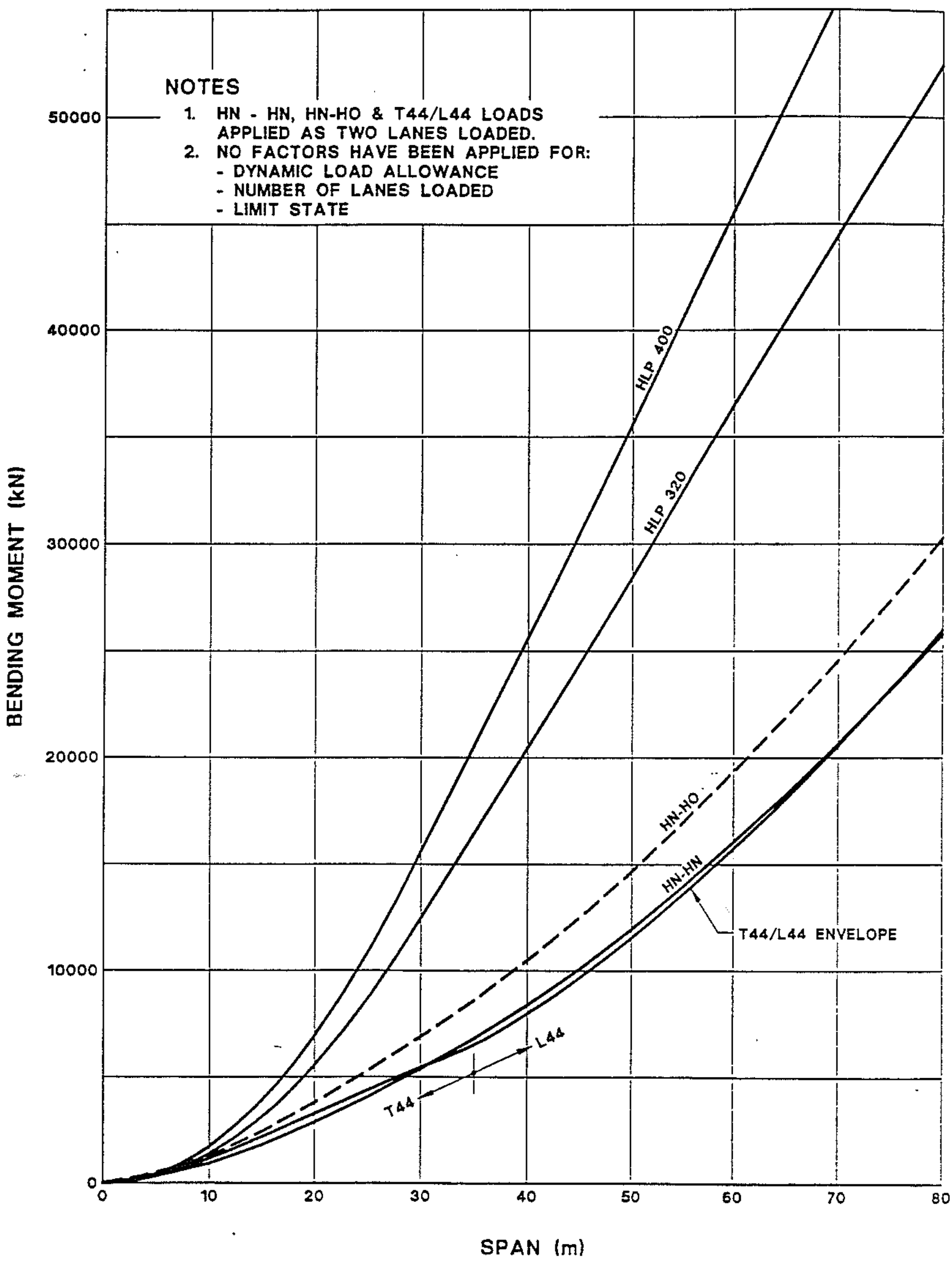


Figure 5 : Unfactored live load bending moments.

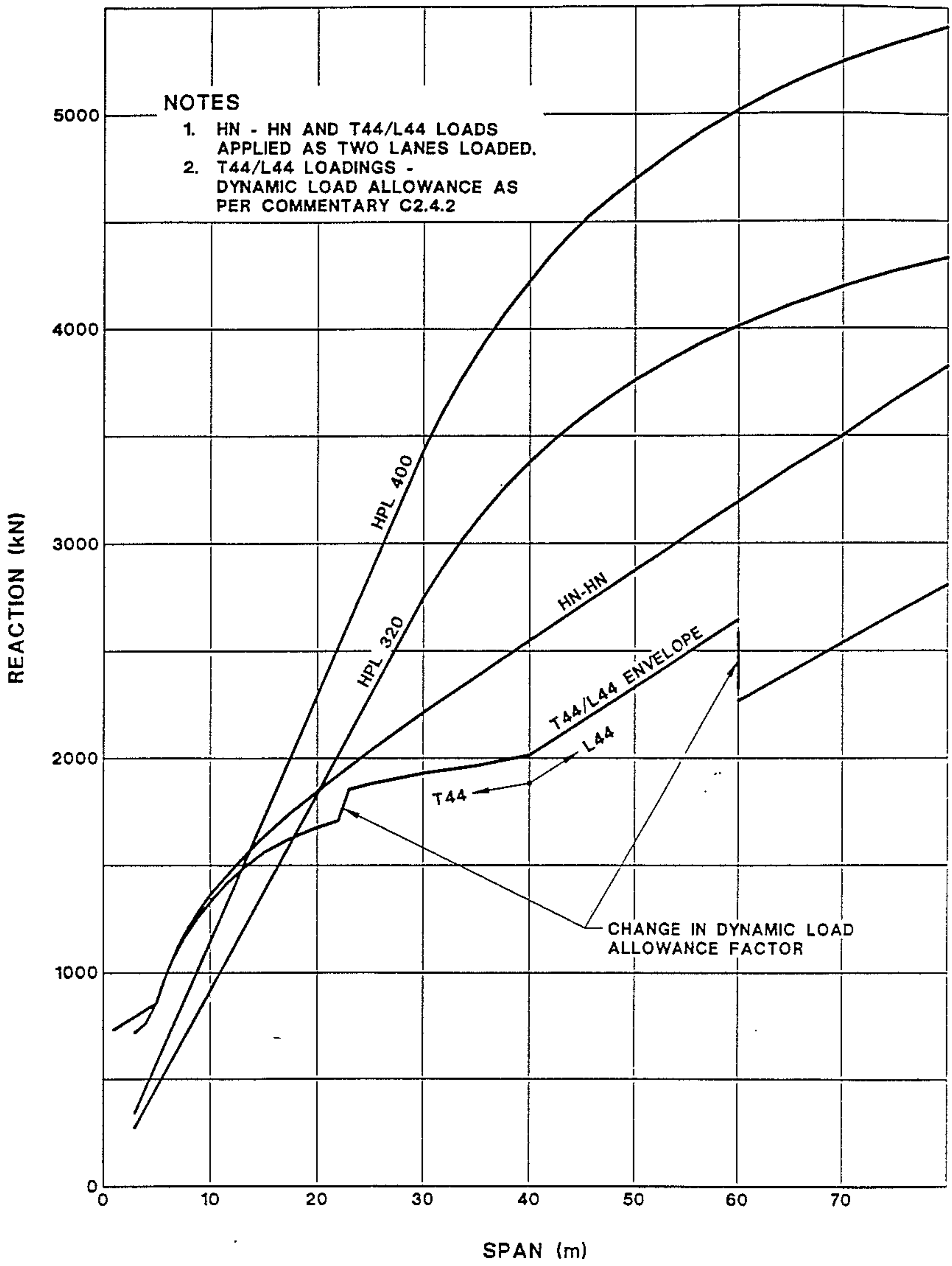


Figure 6 : Ultimate limit state live load reactions.

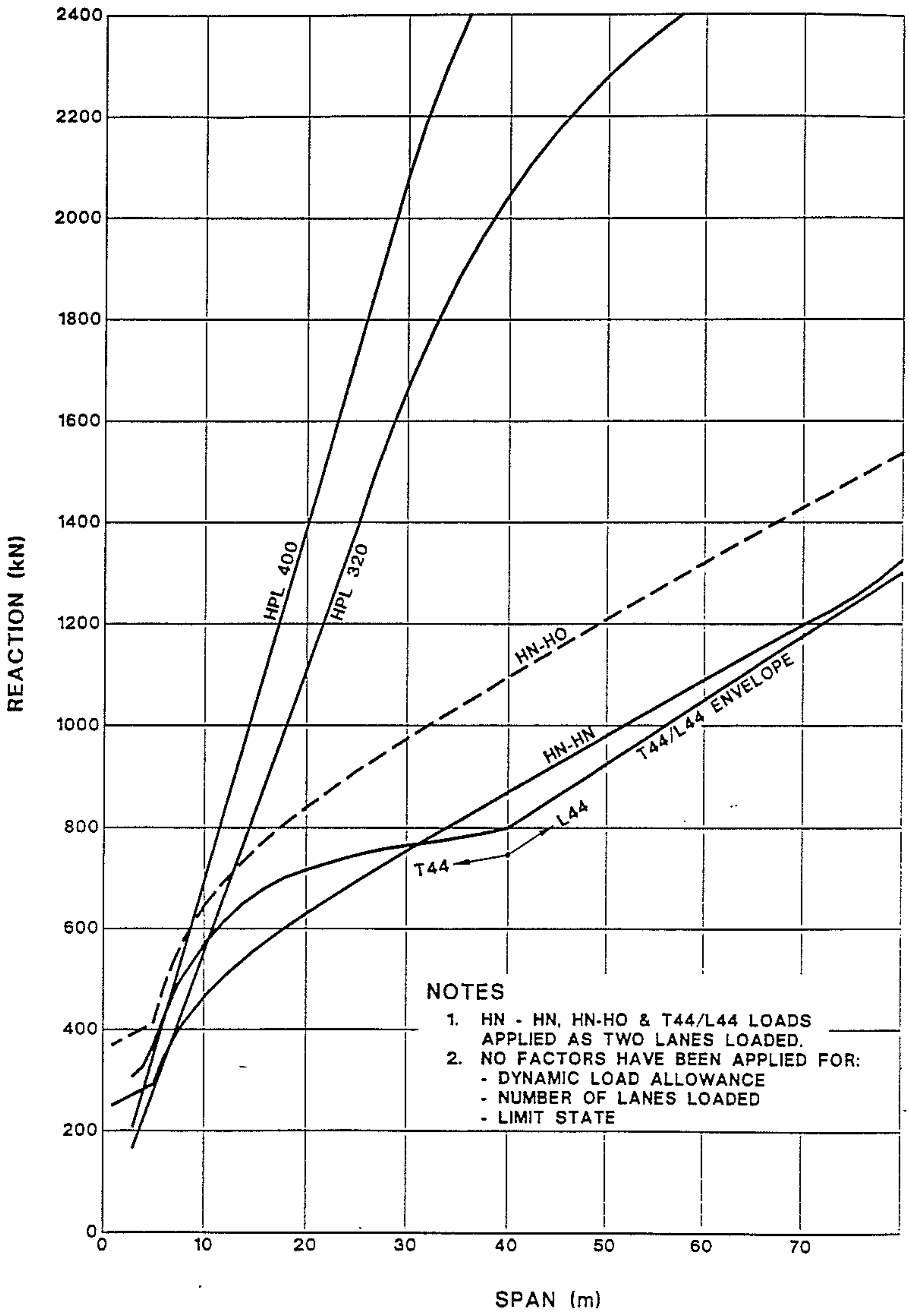


Figure 7 : Unfactored live load reactions.

On principal arterial routes the Austroads Code requires bridges to be designed for the Heavy Load Platform loading, HLP320. For bridges of more than 20m in span length this tends to be a much more severe loading than currently designed for in New Zealand.

8.2.1.2 Discussion and Recommendations

Adoption of the Austroads approach to dynamic load allowance for the normal T44 / L44 loading is not recommended. It is of note that this appears to have been adopted by Austroads from the Ontario Bridge Design Code just at a time when the OHBDC has reverted to a simpler approach of factors related solely to the number of design axles in the lane, with no dependency on structure natural frequency or span. The Ontario Code Commentary provides a detailed discussion of dynamic load allowance which indicates that their earlier relationship has not been invalidated, but refined and simplified. Conclusions from Transit New Zealand's own research into impact factors was that there was little correlation between impact factor and any of the parameters examined, but that the results indicated current design criteria to be conservative at design load level. The Ontario Code together with its supporting references is considered to be the most definitive source of information on dynamic allowance with which the researcher is familiar. Any revision to impact factors should include a review of the Ontario Code material.

Adoption of the Austroads loadings for design of New Zealand bridges would result, for spans greater than 15.0m, in stronger bridges being required for the same span than at present on main arterial routes where HLP loadings have to be designed for. In other situations the design strength required may reduce by less than 10%.

Unfactored, the T44/L44 loading is slightly heavier in its moment effects than the HN loading across the range of spans most common in New Zealand, up to 31m, and then slightly lower up to a span of 74m. By appropriate selection of load and impact factors the T44/L44 loading could probably be matched to provide a similar moment effect across the span range to that currently designed for. There is, however, significant divergence of the T44/L44 shear and reaction effect from that of the HN loading, which requires careful consideration and justification before a change could be recommended. Notably, the T44/L44 plot of reaction against span is not a smooth curve. The HN (and HO) load formulation is also considered to be a simpler formulation to apply from a design perspective.

While there is pressure from the transport industry to permit higher loads, and a study is in progress to assess possible designated heavy transport routes, the HLP 320 loading represents a very heavy load transporter (111 kN/m). Careful consideration will be required before adoption of a loading of this magnitude could be recommended, even for selected routes.

The HN and HO loadings adopted by the Bridge Manual were developed to represent the loading across the span range applied by a vehicle stream complying with the New Zealand Heavy Motor Vehicle Regulations, factored to provide a consistent margin of reserve strength. A more detailed study of how well Austroads Code loadings model the New Zealand legal vehicle stream is required before their adoption could be recommended. Such a study should also compare the Australian and New Zealand legal loads and vehicle configurations and projected future changes to these.

8.2.2 Wheel Load

8.2.2.1 Comparisons

The Bridge Manual design wheel loadings are:

- HN (normal) loading - 60 kN applied to a patch 200mm long x 500mm wide
- HO (overload) loading - 120 kN applied to a patch 600mm long x 900mm wide, or
  - 240 kN applied over a length of 200mm across the full 3.0m lane width

The impact factor applicable to these loads is 1.3.

The Austroads Code design wheel loads are:

- T44 (normal) loading - 24 kN applied to a patch 200mm x 200mm, or
  - 48 kN applied to a patch 200mm long x 400mm wide
- W7 localised load effects - 70 kN applied to a patch 200mm long x 500mm wide
- HLP 320 loading - 50 kN applied to a patch 200mm long x 500mmwide
- HLP 400 loading - 62.5 kN applied to a patch 200mm long x 500mm wide

The W7 loading applies to all decks constructed from materials other than reinforced or prestressed concrete, and to all structural elements (including reinforced and prestressed concrete) for which the critical load is a single dual-tyred wheel load. This would be most situations.

The dynamic load allowance applicable to these loads is not less than 0.25 (equivalent to an impact factor of 1.25).

8.2.2.2 Discussion and Recommendations

More detailed evaluation of the effects of the wheel loading is required before adoption of the Austroads Code design wheel loads could be recommended. For inner deck panels, the Austroads Code design wheel loads may not significantly increase the thickness or reinforcement requirements of new decks relative to past practice. This is as a consequence of the recent introduction to the Bridge Manual of membrane action based on the Ontario Highway Bridge Design Code for deck slab design. Similarly, most existing bridges with decks of full capacity under the old provisions would probably still have adequate capacity for the W7 loading, based on strength assessment using the membrane action approach, though study will be necessary to fully rationalise and verify this. For outside, cantilevered panels, the Austroads Code wheel loading is a 12% increase in demand above the present service design loading.

8.2.3 Fatigue Loading

8.2.3.1 Comparisons

The Bridge Manual currently relies on BS 5400 for its fatigue design loading, which must be derived by a complicated procedure in the absence of an appropriate fatigue design vehicle and suitable charts to simulate New Zealand traffic effects. Derivation of a simplified procedure, based on defined numbers of cycles of a design vehicle configuration, has been the subject of a research study, but simplified criteria are not yet available for incorporation into the Bridge Manual.

The Austroads design fatigue loading is based on defined numbers of cycles of the design normal live loadings (including dynamic load allowance and lane modification factors), dependent on functional class of the route. For fatigue effects on local details it is not entirely clear whether only the wheel loading is considered, or the passage of design vehicles also. Road functional class may not be a good representation of relative traffic densities and likely future traffic growth on routes. From Section Five - Concrete, it appears that the derived stress range for the fatigue vehicle or wheel loading is compared to a limiting permitted stress range corresponding to the number of cycles of loading. (It is presumed that the Steel Section, when available, will classify details and that detail class will also be a factor.) This is a simple design procedure to apply, but is likely to be more conservative than the more precise methods of evaluation adopted by BS 5400.

8.2.3.2 Discussion and Recommendations

For practical design office application a reasonably simple procedure is required. The applicability of the Austroads procedure to New Zealand conditions would need detailed evaluation and probable modification before adoption could be recommended. Adoption as the fatigue loading would also depend on whether T44, L44 and W7 were adopted as the basic design live loads.

The procedure under development by the Transit New Zealand research project (PR3-0075) based on the BS 5400 "single vehicle method" is expected to provide a relatively simple approach that is likely to be less conservative than the Austroads method. It will be adaptable to different route traffic densities.

The design fatigue loading to be adopted will be dependent on the design live loadings adopted and the legal loadings expected to prevail into the future. Adoption of a method based on the BS 5400 "single vehicle method" is recommended. The Austroads approach might also be permitted as a simpler method subject to evaluation showing it to be appropriately conservative.

8.3 Other Traffic Loads

8.3.1 Braking and Traction Loads (TNZ BM Cl. 3.2.1, Austroads Code Cl. 2.5.2)

8.3.1.1 Comparisons

The Bridge Manual provides for both local effects and for effects on the bridge as a whole. For the bridge as a whole the force to be resisted is 10% of the design live load acting on the lanes in one direction for the length of superstructure being considered, but not less than 70% of two HN axle loads (i.e. 168 kN). For a one lane or two opposing lane bridge, the minimum 168 kN force will apply for all bridges whose maximum length of superstructure between expansion joints does not exceed 137m.

The Austroads Code relates design braking force to length of the structure considered, constant at 400 kN for structure lengths up to 20m, increasing linearly to 800 kN for structure lengths up to 60m, and constant at 800 kN for longer structure lengths. The Austroads Code force is independent of bridge width.

8.3.1.2 Discussion and Recommendations

The present Bridge Manual basis, taking into account the total live loading that can be acting in the number of lanes in one direction on a bridge, is considered to be logical and appropriate. Based on comment provided in the Austroads Commentary, the Bridge Manual braking force, as a percentage of the design live load, appears to be low. Retention of the Bridge Manual basis, but revision of the percentages applied to the design live load is recommended.

8.3.2 Centrifugal Force (TNZ BM Cl. 3.2.2, Austroads Code Cl. 2.5.1)

8.3.2.1 Comparisons

Design centrifugal force specified by the Bridge Manual is a radial force derived from the design live load acting at the design speed, modified for the number of lanes loaded, but not by the impact factor. No mention is made of positioning of the HN vehicle element. The force is applied at 2m above the road surface.

Design centrifugal force specified by the Austroads Code is derived from a T44 truck positioned for maximum effect in each traffic lane, acting at the design speed, with no reduction factor for multiple lanes loaded and no impact factor applied. The force is applied at the road surface.

8.3.2.2 Discussion and Recommendations

Neither representation appears ideal. The Bridge Manual appears to cater better for longer bridges where a higher loading may apply than derived from the Austroads Code approach. It is conceivable that worst effects for different elements of a bridge may arise from only having parts of the length of the curve loaded. Also a number of different positions of the HN vehicles may be need to be considered to derive worst effects for different elements of a bridge.

8.3.3 Collision Loads (Austroads Code, Cl. 2.6)

8.3.3.1 Documents Coverage

The Bridge Manual is lacking in requirements for collision load.

The Austroads Code contains a general requirement to design for collision of trains or water-borne craft with the structure where applicable, and for bridges over roads, specifies a design collision load and mode of application to piers not shielded by a rigid barrier. Piers sited well clear of the roadway may be exempt, but the code is not specific on the required clearance. More specific guidance on railway collision loads is provided in the Commentary.

The Austroads Commentary alludes to possible inadequacy in the specified design collision load for road traffic. Also omitted is any requirement for collision loads on bridge superstructures and the need to ensure the integrity of the structure in such an event.

8.3.3.2 Recommendations

The Austroads Code requirements provide an initial basis for further development, but are not considered to be completely adequate. Other codes e.g. BS 5400, should also be reviewed and more comprehensive requirements developed.

8.3.4 Kerb and Barrier Loadings (TNZ BM Appendix B, Austroads Code Cl. 2.7)

8.3.4.1 Documents Coverage

Both the Bridge Manual and the Austroads Code contain detailed requirements for barrier loads and performance. These differ significantly between the documents.

8.3.4.2 Recommendations

Detailed study is required to resolve the differences and what is most appropriate for New Zealand use. As noted previously, a joint Australian - New Zealand working party is understood to be addressing this topic. The possibility of stock applying loading to pedestrian barriers should also be considered.

8.4 Footpath and Cycletrack Loadings (TNZ BM Cl. 3.3.11, Austroads Code Cl. 2.3.9)

8.4.1 Documents Coverage

The Bridge Manual provides comprehensive loadings from pedestrians and cyclists, taking into account whether the footpath or cycletrack is at the same level or raised above the roadway, and whether the load is applied concurrently or non-concurrently with traffic load. Provisions are also included for a vehicle wheel overload acting on the footpath outer edge. Stock loading is not mentioned.

In the Austroads Code pedestrian loading on road bridges is not required to be applied concurrent with traffic loading. Provision is made for isolated vehicle wheel and stock loading, the design load being 20 kN, somewhat less than the 60 kN applied by the Bridge Manual. Specific provisions are included for footbridges.

8.4.2 Recommendations

The Bridge Manual requirements are considered to be more appropriate, but should be reviewed to specifically include footbridges, and to include provisions for stock loading. Stock loading has been a problem on bridges with precast duct covers in footpaths.

8.5 Wind Loads (TNZ BM Cl. 3.3.5, Austroads Code Cl. 2.8 & 2.19)

8.5.1 Documents Coverage

The Bridge Manual refers to NZS 4203: "General Structural Design and Design Loadings for Buildings" for derivation of design wind speeds. As noted previously, New Zealand building standards have been written around a design life of 50 years. Different levels of design wind speed will be appropriate and required for different structures dependent on their design life. In particular, revision is required to define wind loads appropriate to the two limit states for the 100 year design life adopted for bridges. This is an aspect not transferable from the Austroads Code.

In the Bridge Manual, wind forces are calculated according to BS 5400, Part 2, "Specification for Loads". Other than for steel design, BS 5400 is only referred to for isolated design aspects. It would be better if these aspects were incorporated into the Bridge Manual, thus avoiding referral to other documents for isolated aspects.

The Austroads Code provides a basis for determining design wind speeds the code committee have decided as appropriate to Australian conditions.

The Austroads Code approach for derivation of the wind load forces follows the BS 5400 approach but with some departures. The BS 5400 requirements for longitudinal wind load have not been included for valid reasons in respect to road bridges. These reasons are not considered to be valid for pedestrian bridges.

Wind loads for road signs and lighting structures are also included in the Austroads Code, with a requirement to consider excessive vibration due to vortex shedding. The design wind speeds could need modification for New Zealand conditions, and should be related to the design life of these structures.

8.5.2 Recommendations

Requirements for the derivation of design wind speed that are consistent with the limit state philosophy, design lives of the structures, and New Zealand conditions need to be developed. NZS 4203 provides an appropriate basis for this, and caters for a 50 year design life.

For the derivation of wind load on bridge structures the BS 5400 approach should be retained. For the derivation of wind load on poles and signs, the Austroads Code requirements may provide an appropriate basis, but these requirements should be reviewed and compared against other standards (e.g. the relevant British Standards).

Wind load requirements need also to cater for footbridges, including those with roofs and fully enclosed. These are not adequately catered for in the current provisions of either document.

8.6 Thermal Effects (TNZ BM Cl. 3.3.6, Austroads Code Cl. 2.9)

8.6.1 Document Coverage

Both documents provide requirements for the application of temperature loads.

The Bridge Manual defines temperature ranges for concrete and steel structures but neglects timber and other materials. Whether these temperature ranges are appropriate to the ULS and SLS probabilities of exceedence associated with the design is not known.

A single design curve for variation of temperature with depth is provided as a basis for assessment of differential temperature effects.

The Austroads Code defines minimum and maximum bridge temperatures for different combinations of deck and girder construction for steel, concrete and composite bridges, but likewise neglects timber and other materials. For differential temperature, several design curves of temperature variation with depth are given, related to different structural forms. These are generally similar to the NZ curve, but with some variations.

8.6.2 Discussion and Recommendations

A merging of the requirements for the application of temperature loads, and where appropriate tailoring to New Zealand conditions, would be appropriate.

A review and development of design temperature ranges consistent with the limit state philosophy, range of design lives, and New Zealand conditions is needed.

The lack of provisions for bridges in timber and other materials is not considered to be a serious omission. As road bridges, timber bridges are generally being phased out on public roads in favour of more permanent materials. Continued use for pedestrian bridges is, however, likely.

An evaluation of the differences between the Bridge Manual and Austroads Code design curves for differential temperature should be undertaken.

8.7 Water Flow Forces and Effects (TNZ BM Cl. 3.3.8, Austroads Code Cl. 2.10)

8.7.1 Documents Coverage

Both documents adopt essentially similar formulae for derivation of drag forces on piers. In addition the Austroads Code includes provisions for lift type forces acting on piers angled to the water flow, and for drag forces on bridge superstructures. Provisions for debris rafts are similar for bridges not submerged, but submerged bridges are also included in the Austroads Code.

8.7.2 Discussion and Recommendations

The Austroads Code provisions are more comprehensive and adoption as the basis for future development is recommended. Even if inundation is not accepted by Transit New Zealand at the ULS, provisions should be included for this possibility occurring in an extreme event.

8.8 Earth Loads and Effects (TNZ BM Cl. 3.3.9, 3.3.13 & 5.6, Austroads Code Cl. 2.11, 2.17 & 3.4.3)

8.8.1 Documents Coverage

The Bridge Manual requires earth retaining structures to be designed for the more severe of static earth pressures plus live load surcharge or earthquake pressure, including water pressure if drainage is lacking. Live load surcharge is modelled as equivalent to 0.6m of fill. The influence of retaining structure stiffness is considered, in the derivation of soil pressures and wall displacement under seismic loading, an acceptable design basis. Requirements are also included for the treatment of soil pressures providing moment fixity in portal frame structures, for negative skin friction and for loads on foundations induced by plastic deformation, and for consideration of differential settlements and earthquake induced site instability and liquefaction.

The Austroads Code similarly requires earth retaining structures to be designed for static soil pressures, live load surcharge, earthquake effects, and water pressures. The Code is generally more detailed in the derivation of earth pressures, lateral live load surcharge loading and water pressures and includes provision for distribution of wheel loads through fill. No guidance is provided on the derivation of earthquake induced pressures or of the need to consider the influence of structure stiffness on these.

8.8.2 Recommendations

The requirements of both documents are substantially similar but with some differences. Both are also prescriptive in some aspects of their requirements instead of specifying performance. A merging of the two documents' requirements is recommended with a review and conversion of prescriptive requirements to performance criteria. Criteria for earthquake induced effects need expanding. The effects of lateral spreading of soils (e.g. induced by liquefaction) on foundations needs inclusion.

8.9 Frictional Forces and Elastomeric Bearing and Deck Joint Forces (Austroads Code Cl. 2.12)

8.9.1 Documents Coverage

This is omitted from the Bridge Manual except for brief mention in Cl. 3.3.4 dealing with Shortening, and in the Earthquake Resistant Design section Cl. 5.3.4 Member Properties for Analysis, which discusses modelling friction of sliding bearings. It is covered to some extent by the Austroads Code, which provides requirements for consideration of frictional forces on bearings.

In considering friction, the Austroads Code requirements are based on the mean friction values, but neglects friction where it improves the safety of the structure and requires consideration of seizure where that may be critical.

8.9.2 Discussion and Recommendations

Inclusion of a section specifically dealing with consideration of bearing friction and the forces arising from distortion of elastomeric elements is recommended. This section should be located within an overall section dealing with Analysis and Design Criteria, and not within sections dealing more narrowly with Loadings or Earthquake Resistant Design. The Austroads Code provisions provide a basis for this but further development should be undertaken. Requirements should be included for the consideration of forces acting on the structure arising from distortion of elastomeric elements (bearings and deck joints).

Further requirements are needed to cater for situations where material friction values (e.g. initial static friction versus sliding friction) or elastomeric stiffness can vary widely from design mean values, for which consideration of upper and lower bounds should be undertaken.

Frictional restraint, in the Austroads Code, is treated as a loading and has its own load factor assigned to it. This approach is reinforced by its use in another recognised international code, BS 5400. A ULS load factor of 1.3 applied to mean friction values is considered to be low given the variability possible for friction. Over-riding this is the fact that the forces within bearings and other elastomeric elements, and acting through these elements on other parts of the structure, are developed by external loads or by internal effects such as thermal expansion and contraction, concrete shrinkage, and member shortening due to prestress. Treatment of friction at bearings and elastomeric element distortions as loadings is considered to be inappropriate. It is an internal structural action in response to loadings, and the load factors that should apply are those applicable to loadings that mobilise the friction or elastomeric element distortions.

8.10 Shrinkage Creep and Prestress Effects (TNZ BM Cl. 3.3.4, Austroads Code Cl. 2.14)

8.10.1 Documents Coverage

The Austroads Code provides a broad set of requirements while the Bridge Manual deals specifically with the effects of shortening.

8.10.2 Recommendations

A merging of the two documents' requirements would be appropriate. Further long term creep effects considered desirable to have specifically included are the effects of prestress on bridge deck joint gaps and the effect on superstructure dead load deflection in reinforced and prestressed concrete bridges.

The need for consideration of upper and lower bounds should also be reviewed.

8.11 Construction Loads and Effects (TNZ BM Cl. 3.3.7, Austroads Code Cl. 2.16)

8.11.1 Recommendations

The Austroads Code provides the more comprehensive set of requirements and their adoption is recommended. The requirement for checking, during construction, the capacity of the structure for the contractor's actual equipment should be included.

8.12 Earthquake Loads

8.12.1 Documents Coverage and Comparison

Both documents consider earthquake loading only as an ULS condition.

The Bridge Manual sets out comprehensively requirements for the seismic design of bridges including the loadings to be applied for the different forms of analysis permitted, quasi-static analysis, dynamic modal analysis, and dynamic inelastic time-history analysis.

For the quasi-static design method, the design loading is expressed as:

$$V = C_m.Z.R.S_p.W_d$$

Where:

- C_m = basic seismic hazard acceleration coefficient (a function of th structure's fundamental period, the site subsoil category, and th adopted design ductility level)
- Z = zone factor
- R = risk factor (a function of structure importance)
- S_p = structural performance factor (a function of site subsoi category)
- W_d = the participating structural weight (dead load + superimpose dead load) acting in the direction of response being considered

The design seismic hazard spectra are adopted from NZS 4203 "General Structural Design and Design Loadings for Buildings". These are based on a return period of 450 years which has a 20% probability of exceedance in 100 years. Application of the risk factor of 1.3 for structures of highest importance (encompassing all bridges with traffic volumes exceeding 2500 vehicles per day, bridges carrying or crossing motorways or railways, and bridges on most state highways) raises the effective return period to about 1000 years, or 10% probability of exceedance in 100 years.

The maximum level of ductility able to be adopted as the basis for design is a function of the structural form.

The Austroads Code sets out general requirements for seismic design, making reference to dynamic methods of analysis and the need to provide ductility but is inadequate in specifying requirements in these areas.

For the quasi-static design method, the design loading is expressed as:

$$H = \alpha.I.K.C.S.W$$

Where:

- α = zone seismicity factor
- I = importance factor, taken as 1.5 unless the bridge authority directs otherwise
- K = horizontal force factor (equivalent to a structural performance factor, a function of structural form)
- C = seismic response factor ($= 0.06/\sqrt{T}$, i.e. a function of structure fundamental period)
- S = site-structure resonance factor (generally taken as 1.5 unless calculated from AS 2121-1979)

For ULS design, the design force = γ.H where γ = load factor = 1.6.

Figure 8 illustrates the spectrum derived from multiplying together γ.α.C.S for the zone of highest seismicity factor. This is a very low spectrum which suggests either a low seismicity or a ductility factor of the order of 4 to 6 probably being inherent. No statement of inherent ductility factor has been found in the Code or Commentary, but some explanation and explicit requirements in respect to ductility are considered to be warranted if it is inherent.

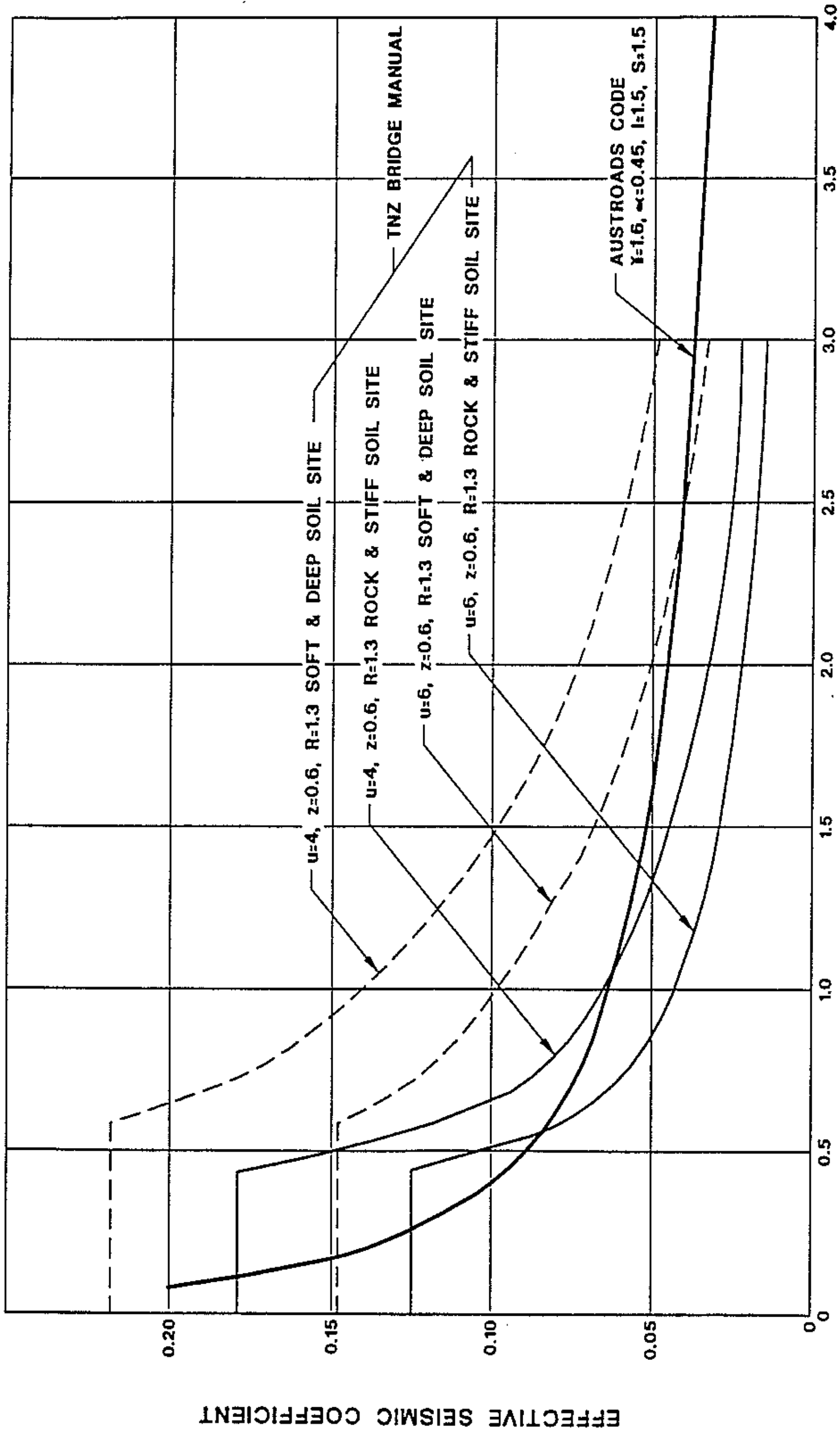


Figure 8 : Comparison of Bridge Manual and Austroads Code seismic coefficient spectra.

8.12.2 Recommendations

The Bridge Manual formulation of seismic loading is considered to be much more comprehensive than that in the Austroads Code, and should be retained. However, the design seismic hazard spectra should be reviewed for revision if an exceedance probability of 5% within the design life is to be consistently applied to the ULS. This is potentially a complex issue, because for seismic response with inelastic ductile behaviour, the ULS does not mean collapse as there is reserve in the ductility capability and greater damping. Generally this is not quantifiable, but usually exists.

The structural performance factor requires research and debate to fully justify the factors currently adopted, and consideration should be given to inclusion of structural form (as in the Austroads Code) as a function contributing to this factor.

8.13 Load Combinations (TNZ BM Cl. 3.4, Austroads Code Cl. 2.17)

8.13.1 Documents Coverage and Comparison

Load combinations in the Bridge Manual are given in Table 3.1 for the Serviceability Limit State, and in Table 3.2 for the Ultimate Limit State. The load cases present, in a traditional manner, combinations of loadings to be considered as possibly acting concurrently on the structure. The derivation of the load factors is not known by the researcher. They are considered to require review and revision to take into account the separate formulation of ULS and SLS loadings (e.g. for wind) and to be calibrated to achieve an appropriate safety index consistent with that adopted in the materials design standards.

The Austroads Code classifies loadings into one of three categories:

- Permanent effects
- Thermal effects
- Transient effects

Load factors applicable to any particular loading differ between limit states, but for each limit state are constant for all load combinations, other than as modified by the SLS load combination factor k (refer below).

Load combinations to be considered are as follows:

For the SLS:

> Permanent Effects + (Serviceability design load for one transient or thermal effect) + k.(Serviceability design load for one or more other transient or thermal effect)
>
> Where k = 0.7 for one additional effect; or 0.5 for two additional effects.

For the ULS:

- Permanent effects + ultimate thermal effects *
- Permanent effects + ultimate traffic load **
- Permanent effects + ultimate wind load **
- Permanent effects + ultimate flood load *
- Permanent effects + earthquake

* Serviceability traffic loads may be included in these combinations, provided that the structure is open to traffic under ultimate conditions.

** Serviceability thermal effects may be included in these combinations when they produce an adverse effect.

Table 3 and Table 4 give a comparison of the Bridge Manual load combinations with their Austroads Code equivalents for standard concrete bridges.

Table 3. SLS loads and load factors (Austroads Code load combinations in italics).

Group	SLS Loads and Load Factors
1A	S = DL + SDL + EP + OW + SG + ST + LLxI + FP *S = DL + 1.3SDL + EP + OW + SG + PS + BF + ST + LL(1+DLA) + 0.7FP*
1B	S = DL + SDL + EP + OW + SG + ST + TP *S = DL + 1.3SDL + EP + OW + SG + PS + BF + ST + TP*
2A	S = DL + SDL + EP + OW + SG + ST + LLxI + FP + HE + TP *S = DL + 1.3SDL + EP + OW + SG + PS + BF + ST + LL(1+DLA) + 0.5FP + 0.5HE + 0.5TP* *Note: The Austroads Code does not define what k factor to use when more than 2 additional transient loads and thermal effects are considered. k=0.5 has been assumed.*
2B	S = DL + SDL + EP + OW + SG + ST + LLxI + FP + HE + WD *S = DL + 1.3SDL + EP + OW + SG + PS + BF + ST + LL(1+DLA) + 0.5FP + 0.5HE + 0.5WD* *S = DL + 1.3SDL + EP + OW + SG + PS + BF + ST + 0.5LL(1+DLA) + 0.5FP + 0.5HE + WD* *Note: The Austroads Code does not define what k factor to use when more than 2 additional transient loads and thermal effects are considered. k=0.5 has been assumed.*
2C	S = DL + SDL + EP + FW + SG + ST + LLxI + FP + HE *S = DL + 1.3SDL + EP + FW + SG + PS + BF + ST + LL(1+DLA) + 0.5FP + 0.5HE*
3A	S = DL + SDL + EP + OW + SG + ST + EQ + 0.33TP *S = DL + 1.3SDL + EP + OW + SG + PS + BF + ST + EQ + 0.7TP.*
3B	S = DL + SDL + EP + FW + SG + ST + WD *S = DL + 1.3SDL + EP + FW + SG + PS + BF + ST+ 0.7WD* *S = DL + 1.3SDL + EP + 0.7FW + SG + PS + BF + ST + WD.*
4	S = DL + SDL + EP + OW + SG + ST + OLxI + 0.5 FP + 0.33TP *S = DL + 1.3SDL + EP + OW + SG + PS + BF + ST + OL(1+DLA) + 0.5FP + 0.5TP*

Note: Further load combinations are possible under the Austroads Code formulation. Only those most closely corresponding to Bridge Manual load combinations and likely to be critical are listed above. See notes to Table 4.

Table 4. ULS loads and load factors (with Austroads Code load combinations in italics).

Group	ULS Loads and Load Factors
1A	U = 1.35DL + 1.35SDL + 1.82EP + 1.35OW + 1.35SG + 1.35ST + 2.25LLxI + 1.75FP *U = 1.2DL + 2.0SDL + (1.25-1.70)EP + OW + 1.2SG + 1.0PS +1.3BF + 1.5ST + 2.0LL(1+DLA) + 2.0HE*$_c$ *+ 2.0FP* *Note: Footpath loading not specifically included in the Austroads Code ULS load combinations*
1B	U = 1.35DL + 1.35SDL + 1.82EP + 1.35OW + 1.35SG + 1.35ST + 1.69TP *U = 1.2DL + 2.0SDL + (1.25-1.70)EP + OW + 1.2SG + 1.0PS + 1.3BF + 1.5ST + 1.25ST* *Note: Temperature alone as a transient load / thermal effect is not specifically included in the Austroads Code ULS load combinations*
2A	U = 1.20DL + 1.20SDL + 1.20EP + 1.20OW + 1.20SG + 1.20ST + 1.20LLxI + 1.20FP + 1.20HE + 1.20TP *U = 1.2DL + 2.0SDL + (1.25-1.70)EP + OW + 1.2SG + 1.0PS +1.3BF + 1.5ST + 2.0LL(1+DLA) + 2.0HE*$_c$ *+ 1.5HE*$_b$ *+ TP* *Note: Traffic braking forces not specifically included in Austroads Code ULS load combinations*
2B	U = 1.35DL + 1.35SDL + 1.35EP + 1.35OW + 1.35SG + 1.35ST + 1.35LLxI + 1.35FP + 1.35HE + 1.35WD *U = 1.2DL + 2.0SDL + (1.25-1.70)EP + OW + 1.2SG + 1.0PS + 1.3BG + 1.5ST + 2.0LL(1+DLA) + 2.0HE*$_c$ *+ 1.5 HE*$_b$*+ WD* *Note: Wind not combined with traffic load in the Austroads Code ULS load combination*
2C	U = 1.35DL + 1.35SDL + 1.35EP + 1.35FW + 1.35SG + 1.35ST + 1.35LLxI + 1.35FP + 1.35HE *U = 1.2DL + 2.0SDL + (1.25-1.70)EP + FW + 1.2SG + 1.0PS + 1.3BF + 1.5ST + 1.0LL(1+DLA) + 1.0HE*$_c$ *+ 1.0He*$_b$ *Note: Traffic braking not combined with flood load in the Austroads Code ULS load combination*
3A	U = (0.8-1.3)DL + (0.8-1.3)SDL + 1.35EP + 1.35OW + 1.0SG + 1.0 ST + 1.0EQ + 0.33TP *U = 1.2DL + 2.0SDL + (1.25-1.70)EP + OW + 1.2SG + 1.0PS + 1.3BF + 1.5ST + 1.6EQ + 1.0TP* *Note: Temperature effects not specifically combined with earthquake in the Austroads Code ULS load combination*
3B	U = 1.10DL + 1.10SDL + 1.37EP + 1.37FW + 1.10SG + 1.10ST + 1.37WD *U = 1.2DL + 2.0SDL + (1.25-1.70)EP + FW + 1.2SG + 1.0PS + 1.3BF + 1.5ST + 1.0LL(1+DLA) + 1.0He*$_c$ *U = 1.2DL + 2.0SDL + (1.25-1.70)EP + OW + 1.2SG + 1.0PS + 1.3BF + 1.5ST + WD + 1.0TP* *Note: In the Austroads Code ULS load combinations flood loading and wind loading are not combined; flood loading being combined with live load, and wind load with temperature effects.*
4	U = 1.35DL +1.35SDL +1.35OW + 1.35SG +1.35ST + 1.48OLxI + 0.70FP + 0.33TP *U = 1.2DL +2.0SDL + OW + 1.2SG + 1.0PS + 1.3BF + 1.5ST + 1.5HLP(1+DLA) + 2.0HE*$_c$ *+ 2.0FP+ 1.0TP* *Note: Footpath loading not explicitly included in Austroads Code ULS load combinations.*

Notes to Table 3 and Table 4:

- Construction load cases (Bridge Manual load groups 5A, 5B and 5C) are omitted as these do not seem to be defined by the Austroads Code.

(Notes to Tables 3 and 4 continued)

- Symbols used are those adopted in the Bridge Manual. Additional symbols used are:

PS	=	secondary effects arising from prestressing
BF	=	forces arising from frictional restraint or elastomeric distortion in bearings
HLP	=	heavy load platform
DLA	=	dynamic load allowance

- T44 and L44 loads have been treated as normal live load (LL) and HPL vehicle loading as an overload (OL).

- The Austroads Code treats normal water flow loads and buoyancy as a permanent effect but doesn't define any load factors associated with it. Likewise, no load factors seem to be defined for the SLS and ULS flood flow loads or wind loads.

- Austroads Code load factors applicable to earth pressure loads and horizontal forces due to traffic are dependent on the nature of the forces. Thus, the range of the load factor is indicated.

As can be seen from the above tables and the comments contained therein, there is considerable variation between the Bridge Manual and the Austroads Code, both in terms of the load factors applied and in terms of the individual loadings combined to form combinations.

The Austroads Code does not specifically list horizontal forces due to traffic as an individual transient effect. Nor does it spell out how this effect is to be treated in conjunction with gravity traffic loads. It is considered that centrifugal force should be treated as an integral component of the "traffic load", while braking and acceleration forces should be considered as a separate transient effect but one which can only be applicable in combination with the "traffic load". This interpretation has been applied in the above tables, as indicated by the subscripts applied to the HE load. The application of centrifugal force is equally poorly defined in the Bridge Manual.

As noted in section 8.9, the inclusion by the Austroads Code of bearing friction as a loading with its own load factor is not considered to be appropriate.

At ULS, the Austroads Code does not seem to consider:

- wind acting concurrently with flooding
- traffic acting concurrently with wind
- footpath loading acting concurrently with traffic

The Austroads Code is felt to be incomplete and vague in its specification of ULS load combinations. This is illustrated by the following form of phrases used:

"The Ultimate Limit state load combinations ...*include*: ....."

"... loads / effects *may* be included in these combinations ..."

8.13.2 Recommendations

The ideal manual should be specific on the load combinations to be considered and on how those component loads are to be combined. The Austroads Code does not measure up in this regard.

The Austroads format for load combinations, while having some appeal in its apparent simplicity, is potentially too simplistic. Detailed consideration needs to be given to what loadings have a reasonable likelihood of acting concurrently at some time in the life of the structure. The load factors also require calibration against New Zealand conditions to ensure consistency of the safety index.

A comprehensive study is needed to develop appropriate load combinations with a consistent safety index applicable to New Zealand conditions. Adoption of the Austroads Code format for these is not supported without detailed study and modification.

8.14 Dynamic Behaviour (TNZ BM Cl. 3.3.12, Austroads Code Cl. 2.18 & 2.19)

8.14.1 Documents Coverage

The Bridge Manual requires all bridges to be assessed for vibration. Compliance with the limiting vibration criteria is mandatory for bridges carrying significant pedestrian traffic, but for other bridges compliance is required only where economically justified. The procedure is based on a detailed assessment of dynamic response.

By comparison, the Austroads approach is to categorise bridges into those with public footways and those without and to apply different criteria to each category. The procedure is based on simple assessment of the static deflection and natural frequency of vibration of the structure.

The methods adopted for assessment of footbridges, though slightly different between the documents, are essentially similar and complex.

8.14.2 Recommendations

Both documents appear to provide adequate requirements. The Austroads Code requirements are preferred on the basis of appearing simpler to apply without any obvious loss in adequacy. It is recommended the Austroads Code requirements be reviewed in detail with a view to adoption.

9. STRUCTURAL DESIGN OF ELEMENTS

9.1 Methods of Analysis and Structural Modelling

9.1.1 Documents Coverage

The Bridge Manual (Cl. 4.1) requires the analysis methods used to take account of relative stiffness of longitudinal and transverse members; and the stiffnesses used for reinforced concrete members to take account of the effects of flexural cracking. In addition, NZS 3101, the adopted code for concrete design, contains a range of requirements related to structural modelling and analysis including coverage of:

- Redistribution of design moments obtained by elastic analysis for design for the ULS;
- Moments to be adopted for design at supports and beam-column junctions ;
- Modelling of span lengths;
- Modelling of effective flange width of T-beams; and
- The use of strut and tie models for analysis of squat elements and regions of discontinuity.

The Bridge Manual includes an empirical method for the design of deck slab panels based on membrane action (Cl. 4.2.2). Requirements are also included for structural analysis for earthquake response (Cl. 5.3.3 and 5.3.4), encompassing:

- Methods of analysis, criteria for requiring their use, and requirements in regard to the manner of their application; and
- Member properties for concrete members, PTFE/stainless steel bearings, and consideration of variation in material properties.

For individual elements, a range of requirements are to be found in the Bridge Manual in respect to their modelling, particularly within the Earthquake Resistant Design section.

Analysis and modelling criteria in the Austroads Code are contained in sections dealing with specific elements or materials. In many instances methods are prescribed or design guidance is included. Part 3, Foundations, includes:

- Modelling of soil and surcharge pressures on structures, and of pressures under foundations at the SLS.
- Requirements on the types of analysis to be used in respect to different types of foundations.
- Methods for the calculation of pile settlements and lateral deflection for both single piles and piles in groups.
- Methods for modelling the resistance of ground anchors; and
- Methods for modelling the structural action of various types of retaining wall.

Much of the material in Part 3 on this topic is somewhat general and non-specific in nature and more in the form of guidance than of Code specification of requirements. The use of the terminology: ".. *may be* .." and " .. *should be* .." occur often. This material should be moved to the Commentary.

Part 4, Bearings and Deck Joints, defines the coefficients of friction to be used in modelling various types of bearings (Cl. 4.9). Single values are given, with no consideration given to possible variability. Methods are given for the calculation of elastomeric bearing stiffnesses (Cl. 4.12.10) and guidance provided on selection of elastic moduli and provision for creep (Cl. 4.12.11 & 4.12.12).

Part 5, Concrete, contains a section dedicated to Methods of Structural Analysis (Section 5.7). Methods of analysis to be used for different forms and parts of the structure are specified, together with considerations to be taken into account. Methods of analysis covered within this section include:

- For reinforced and prestressed concrete structures, including frames and slabs:
  Static analysis for determinate structures;
  - Linear elastic analysis;
  - Elastic analysis incorporating secondary bending moments due to lateral joint displacement; and
  - Rigorous structural analysis.
- For frames and slabs:
  - Plastic analysis.

For linear elastic analysis, requirements are given for the stiffnesses to be assumed in analysis.

Section 5.12, Design of Non-flexural Members, End Zones and Bearing Surfaces includes requirements for use of the following forms of analysis, and requirements to be satisfied for the methods to be applicable:

- Strut and tie model;
- Stress analysis;
- Empirical methods.

9.1.2 Discussion and Recommendations

In both documents, modelling for structural analysis is predominantly covered within the requirements for design in concrete. These cover the analysis methods to be used, the redistribution of design moments, moments to be adopted for design at supports, modelling of span lengths, and the use of strut and tie models. The requirements appear to be generally similar, but there are differences which will require detailed study to define properly. There is a separate joint Australian / New Zealand Standards

Associations project to harmonise concrete codes between the two countries, which is expected to address this.

The Bridge Manual has specifically adopted the empirical membrane action approach for the design of interior deck slab panels, based on an evaluation of this method contained in the Ontario Highway Bridge Design Code. This is not included in NZS 3101, Concrete Structures Standard, or in the Austroads Code, but should be retained in a new design manual.

For bearings and joints, consideration of the upper and lower bounds of stiffness should be required. As with other materials, this is particularly significant to the earthquake resistant design of the structure (refer to comments section in 7.9).

The Bridge Manual's requirements for structural modelling and analysis for earthquake resistant design are largely absent from the Austroads Code and should be retained.

9.2 Main Structural Elements

9.2.1 Documents Coverage

Both the Bridge Manual and the Austroads Codes deal with the design of the main structural members (piers, beams and slabs) principally within their materials design codes. Consequently, criteria for the materials design of these elements is covered within the discussion of materials design criteria.

Within the Bridge Manual, criteria for the design of structural elements is dispersed among the different sections, although they are mainly in Section 4: Analysis and Design Criteria and Section 5: Earthquake Resistant Design.

9.2.2 Discussion and Recommendations

Consideration should be given to whether the present presentation is the most appropriate, or whether each element's design and performance criteria should be grouped together. As a comparison, NZS 3101, Concrete Structures Standard, in its sections deals with the basic criteria for element design and then provides additional design requirements for earthquake effects.

9.3 Foundations

9.3.1 Documents Coverage (TNZ BM Cl. 1.2, 2.4, 4.8, 5.1 & 5.4, Austroads Code Section 3)

The Bridge Manual requires site investigations to be undertaken, sufficient to ensure safe, economical and practical design to be developed. Normally these comprise three stages:

- Prior to finalisation of the Design Statement, sufficient to enable sound judgement to be made on all aspects of design;
- Prior to final design, detailed field investigations and laboratory testing; and
- During construction, as appropriate.

The information is to be presented in an Investigation Report. Borelogs, soil descriptions and testing are required to comply with current practice as presented in documents published by Standards New Zealand, New Zealand Geomechanics Society and the like.

For design of foundations and retaining structures, either working stress or strength properties of the soils may be used. Minimum factors of safety against overturning, and against sliding, unless specifically designed for movement, are specified for free-standing structures. Ranges of strength reduction factors and safety factors for foundation design, based on type of data used as the basis, are specified.

Within practical and economic constraints, mitigation measures are to be incorporated for the effects of large movements or liquefaction that may affect bridges located in areas susceptible to earthquake induced liquefaction or which cross active faults of recurrence interval less than or equal to 2000 years.

Cl. 5.4 of the Bridge Manual deals with the modelling and design of foundation elements for earthquake resistance. These requirements generally reflect the application of "capacity design" principles for earthquake, but also include more general requirements which should be located more appropriately in a section of the document related to the general structural design of these elements. Encompassed are:

- Structures anchored to friction slabs;
- Structures "locked-in" to the ground longitudinally;
- Structures on pile / cylinder foundations;
- Structures on spread footing foundations;
- Structures on rocking foundations.

Generally omitted from the Bridge Manual are requirements for ground anchors (e.g. fatigue performance, access for inspection and maintenance).

Additionally, NZS 3101, Concrete Structures Standard, specifies requirements for the design of foundations, in particular for earthquake resistance (Cl. 4.4.11) and for the structural detailing of reinforced concrete foundation elements (Section 15).

The Austroads Code devotes its Section 3 specifically to the design of foundations, earth retaining structures and buried structures.

Geotechnical categories are defined as a basis for deciding the minimum requirements for the extent and quality of geotechnical investigation, calculations and construction control checks required. Guidance is included on the presentation of geotechnical reports and on information to be supplied to contractors.

A statement of the design philosophy setting out the application of limit states to foundation design is provided. Material strength reduction factors are included, varied over a wide range of foundation types and according to types of information used as the basis.

Methods for the derivation of earth pressures, including pressures due to surcharge loads are prescribed in the Austroads Code.

Durability is discussed, encompassing concrete steel and timber, with guidance included on corrosion allowances for steel embedded in neutral soils.

Specific requirements are given for the performance of each of the foundation types - shallow foundations, deep foundations, and anchorages. These requirements generally apply an ultimate limit state approach to evaluation of strength.

Minimum requirements are included for the structural design of precast reinforced and prestressed concrete piles, casting place concrete piles, and steel piles.

9.3.2 Discussion and Recommendations

As an overall comment, Section 3 of the Austroads Code is considered to be unsatisfactory for Transit New Zealand use. It abounds with the use of the words ".. *may* .." and ".. *should* ..", indicative of providing guidance to users. As such it would contravene Transit New Zealand policy of not providing design guidance in its Bridge Manual, if adopted. It also prescribes design methods. Section 3 should be written more clearly in the form of specifying mandatory performance requirements, and the design methods and guidance should be removed to the Commentary, or removed altogether.

The Austroads requirements range from generalised statements to specific recommendations of particular formulae and analysis methods. In many cases these are not consistent with generally adopted New Zealand practice as set out, for example, in New Zealand Geomechanics Society and the former Ministry of Works and Development publications. Considerable qualification and augmentation of the Austroads requirements would probably be required to make them appropriate for adoption for use in a Transit New Zealand design manual.

For the Austroads Code for piles, some inadequacies apparent in the specified requirements include:

- lack of specificity in the conditions under which buckling has to be considered;
- lack of definition of the coefficient l in the equations for pile lateral resistance; and

- lack of consideration of leading piles shielding trailing piles in considering the lateral resistance of pile groups, covered only by a very general requirement to consider group effects.

The present Bridge Manual specifications for foundations requires revision to include more in the way of specific criteria for the design of foundation elements. This may be achieved through reference to appropriate existing standards. Criteria are required for ground anchors encompassing their protection, and access for their inspection during their life. Also, aspects of earthquake resistant design possibly requiring more comprehensive or positive statements include:

- Ground improvement for reduction of liquefaction potential;
- Selection of appropriate soil stiffness values reflecting limit state pile stiffness degradation; and
- Effects of lateral spreading due to liquefaction, particularly on raked pile supports.

A detailed review of foundation design criteria is recommended, which should include a review of the range of recognised applicable design standards including the Austroads Code. The Austroads Code is not considered suitable for adoption in its present form without significant modification.

9.4 Abutments and Retaining Walls (TNZ BM Cl. 4.10, Austroads Code Cl. 3.9.5, 3.9.7, & 3.9.8)

9.4.1 Documents Coverage

Clause 4.10 of the Bridge Manual sets out requirements for the design of integral and semi-integral abutments. Limitations are placed on the continuous length of bridge with which these forms of abutment may be used. Surrounding soils are required to be sufficiently flexible to accommodate superstructure length changes without distress.

Section 5: Earthquake Resistant Design contains a range of criteria for the seismic design of abutments and retaining walls associated with bridges. They encompass the design of friction slabs (Cl. 5.4.4); the design of structures locked in to the ground (Cl. 5.4.5); earth pressures and structural inertia forces on abutments and retaining walls to be designed for (Cl. 5.6), and performance of abutments and retaining walls (Cl. 5.6.3). The influence of wall stiffness has to be taken into account in determining design earth pressures. Abutments and tied-back walls are to be designed to remain elastic under design earthquake loading. Other walls may be designed to perform either elastically with no permanent displacement under earthquake response, or to undergo permanent outward displacement, dependent on the type of wall. Criteria for outward movement permitted are specified for free standing walls and mechanically stabilised walls.

Section 3: Foundations of the Austroads Code deals with the design of abutments and retaining walls encompassing design loads, stability and structural design (Cl. 3.9.1) and detailing (Cl. 3.9.3). The effects of scour or excavation removing stabilising soil are to be considered. Detailing includes provisions for shrinkage and thermal movement joints and reinforcement, provisions for drainage, and provisions for wall batters. For locked-in structures, the effects of differential pressures acting at the abutments are to be considered. Requirements are included for the general structural design of elements for a variety of forms of wall including cantilever walls, counterfort and buttressed walls, crib walls , reinforced soil walls and sheet pile walls.

9.4.2 Discussion and Recommendations

The Bridge Manual provides the better base for future development of requirements for abutments and retaining walls.

Comment received by Transit New Zealand has questioned the adequacy of the existing requirements in dealing with crib walls and possible inconsistency in requiring the use of the strength method while specifying working stress design factors of safety. The present requirements need review for these aspects, and for their expression in terms of current accepted practice in respect to the application of limit state philosophy.
Extension of the present requirements to provide coverage of the various retaining wall types is recommended. The Austroads Code provides a basis for this but should be reviewed in conjunction with other sources and expressed appropriately in Code format requirements with design guidance generally removed.

9.5 Embankments and Cuttings (TNZ BM Cl. 2.5 & 4.9, Austroads Code Cl. 3.4.3)

9.5.1 Documents Coverage

The Bridge Manual requires the designer to consider the influence of approach embankments and cuttings on the bridge structure, including:

- Immediate gravity effects;
- Seismic effects;
- Long term settlement effects; and
- Loading from slope material which may fall onto the deck.

The effects of approach settlement on the riding characteristics, traffic safety and performance of abutment components are required to be considered.

Minimum factors of safety (assumed to be against failure) are specified for embankment static behaviour, and suitable monitoring is to be undertaken where stage loading, sand drains or other techniques are used to construct embankments or to induce accelerated settlement.

Assessments are to be made of the potential for embankment materials and underlying foundation materials to lose strength during or after an earthquake or flooding, of the manner and extent of failure, and of the risk, feasibility and cost of mitigating against these effects. Embankments able to act as water retaining structures are to satisfy minimum factors of safety against water seepage and drawdown effects.

Earth pressure loadings and negative skin friction effects on foundations are to be taken into account. Cuttings slopes are to be designed to ensure slope failure material will not be deposited on the bridge, or where impractical, the bridge is to be designed for such loading.

Where bridges can be affected by instability or creep of natural ground, mitigation measures are to be applied.

The Austroads Code does not contain equivalent requirements in respect to approach embankments and cuttings, other than as contained in Cl. 3.4.3, Loads and Earth Pressures. This clause requires the inclusion of water pressure loads caused by hydrostatic and seepage pressure, down drag forces due to soil settlement around piles; and drag loads on piles caused by lateral soil movements where substantial embankments are placed over areas with compressible sub-surface layers.

9.5.2 Recommendations

Retention of the present Bridge Manual requirements is recommended. For a Road Structures Design Manual, further development of the requirements would be desirable to cater more specifically for the assessment of embankment stability, cut slope stability, and mitigation measures for creep and instability of natural ground, in different ground materials. Review and consideration of appropriate accepted standards for adoption is recommended.

9.6 Culverts and Subways (TNZ BM Cl. 2.3, Austroads Code Cl. 1.2 & 3.9.6)

9.6.1 Documents Coverage

Neither document covers corrugated metal plate culvert or arch type structures or concrete drainage pipes. The Bridge Manual specifically excludes corrugated steel plate culverts. The Austroads Code, Cl. 3.4.3.4 and Cl. 3.9.6.1, refers to AS 2041, AS 2042, AS 3703, AS 1342 and AS 3721 for the design of these structures.

In the Bridge Manual, requirements for culvert waterway design are given in Cl. 2.3, which requires the culvert to pass a 10 year return period flood without heading up, and a 100 year return period flood with heading up to a maximum level 0.5m below road surface level. These requirements are relaxed for routes carrying less than 750 vehicles per day. Embankment stability under flood conditions is to be ensured, and adequate protection provided against piping and scour. Section 5: Earthquake Resistant Design includes requirements for the design of structures locked in to the ground which apply to these form of structures.

Austroads Code Cl. 1.2.7 requires culverts to be designed to resist hydraulic forces under flooding, to be protected from undermining, and to be stabilised at their downstream end against embankment overtopping. The size and amount of debris to be catered for is also to be considered. Cl. 3.9.6 sets out loads to be designed for and recommends the use of flexible footing analysis for the design of base slabs.

9.6.2 Discussion and Recommendations

For culvert and subway design the Austroads Code provides the better basis for future development. Requirements need to be incorporated for the performance of corrugated metal (steel and aluminium) plate culverts and arches, and for pipe culverts. The Australian Standards referenced by the Austroads Code should be reviewed for suitability for adoption. Culvert waterway capacity needs to be related to the philosophy adopted for river crossing serviceability (refer to 7.3 above).

As culverts can be buried beneath deep fills where their replacement is extremely difficult, requirements for provision for their long term serviceability and maintenance should also be included.

9.7 Bearings(TNZ BM Cl. 4.7 & 4.11.1, Austroads Code Section 4)

9.7.1 Document Coverage

The Bridge Manual contains design criteria only for the design of elastomeric bearings, for which conformance with either AS 1523 or the UK Department of the Environment technical memorandum BE 1/76 are specified. Where the superstructure rests on bearings, the overall arrangement is to be such that the superstructure can be jacked up for bearings to be removed and replaced.

The Austroads Code devotes the bulk of section 4 to a comprehensive specification for bearings, including requirements in relation to:

- Loads and movements;
- Provisions for durability, access, handling, resetting and replacement;
- Movement restraints;

- Alignment of bearings;
- Anchorage of bearings;
- Design considerations;
- Loading resulting from resistance to movement;
- Design of rocker and roller bearings;
- Design of knuckle leaf bearings;
- Design of elastomeric bearings; and
- Proprietary bearings (including pot bearings and sliding bearings).

9.7.2 Discussion and Recommendations

The Austroads Code provides the more comprehensive treatment of bearings and thus the better basis for future development. However, a review and consideration of other recognised codes, in particular a detailed review of BS 5400 Parts 9.1 and 9.2 is recommended. The Austroads Code requirements for elastomeric bearing design appear to be similar to those adopted by the Bridge Manual. A detailed review should, however, be undertaken to compare the requirements for elastomeric bearings of the two documents and to explain any significant differences identified. AS 1523 is also under revision as a joint Australian - New Zealand Code. This should also be included in the review when published.

Inclusion of additional requirements for minimum edge distance of bearing plates from the edge of concrete members is recommended.

A review is recommended of the different concrete design codes for requirements for the bearing stress applied to concrete surfaces. Consideration should be given to the need for additional concrete design criteria for the provision and design of confining reinforcement at bearing locations.

9.8 Mechanical Energy Dissipation Devices and Load Limiting Devices

9.8.1 Documents Coverage (TNZ BM Cl. 5.4.9)

The Bridge Manual provides limited coverage of mechanical energy dissipating devices in Section 5: Earthquake Resistant Design. Structures incorporating these devices are required to be designed in a similar manner to a ductile structure. The energy dissipating devices are to have their performance substantiated by testing. Their long term functioning is to be assured by protection from corrosion and water and debris build-up. The devices are to be accessible for inspection and maintenance, and are to be removable and replaceable.

Requirements for such devices are entirely absent from the Austroads Code.

9.8.2 Discussion and Recommendations

The present Bridge Manual requirements should be retained and extended to include requirements for load limiting devices (e.g. abutment knock-off elements). A review should be included of other recognised codes and sources of information (e.g. AASHTO, Caltrans practice) for requirements that may have been developed.

9.9 Deck Joints (TNZ BM Cl. 4.11.4, 4.11.7 & 5.5.1, Austroads Code Section 4)

9.9.1 Documents Coverage

The Bridge Manual requires deck expansion joints to be watertight unless specific provision is otherwise made to collect and dispose of water. Expansion joints and structural detailing are also to be such that the expansion joints can be installed after completion of the adjacent deck slabs. Full design earthquake response movements need not be provided for, subject to damage being limited to sacrificial devices permitting minor damage in a predetermined manner. Damage to deck joint seals under earthquake response is acceptable provided mechanical damage to the deck joints is avoided.

The Austroads Code includes comprehensive requirements for deck joints encompassing:

- General requirements (including traffickability and noise generation);
- Design loadings to be resisted;
- Design movement and future overlays to be accommodated;
- Anchorage of the deck joints;
- Drainage (which requires either an additional water barrier system or a drainage system to be provided);
- Joint sealing material and fillers;
- Installation; and
- Proprietary deck joints.

9.9.2 Recommendations

The requirements of the two documents have little in common and are generally complimentary. It is recommended that they be reviewed and amalgamated in a new Transit New Zealand Road Structures Design Manual.

9.10 Settlement Slabs (TNZ BM Cl. 4.11.3)

9.10.1 Documents Coverage

The Bridge Manual requires settlement slabs to be provided at all abutments supporting earth fill and sets out requirements for their design.

Coverage of settlement slabs is absent from the Austroads Code.

9.10.2 Recommendation

The existing Bridge Manual requirements should be retained.

9.11 Ancilliary Bridge Items (TNZ BM Cl. 5.5.2 & 5.5.4)

9.11.1 Documents Coverage

Encompassed within this topic is such items as linkage bolts, holding down bolts, and buffers to absorb impact under earthquake response.

The Bridge Manual contains requirements for the provision of linkage systems to provide security of all spans against loss during earthquake. Requirements are provided for both loose and tight horizontal linkage systems. Holding down devices are also to be provided where, under design earthquake conditions the net vertical reaction is less than 50% of the dead load reaction.

The Austroads Code contains no similar requirements.

9.11.2 Recommendations

The existing Bridge Manual requirements should be retained. Additional requirements should also be developed and incorporated to ensure the integrity of bridge structures under extreme flood conditions and collision events.

9.12 Date and Loading Panel (TNZ BM Cl. 4.11.6)

9.12.1 Documents Coverage

The Bridge Manual requires all bridges to have a durable panel fixed to each end of the bridge displaying the year of construction and the design traffic loading.

The Austroads Code contains no similar requirement.

9.12.2 Recommendation

The existing Bridge Manual requirement should be retained.

9.13 Light Poles and Signs

9.13.1 Documents Coverage

Apart from specification of design loadings contained in the Austroads Code, neither document contains requirements specific to the design of light poles and signs.

Transit New Zealand has adopted NZS 6701:1983 as a guideline for the design of roadway lighting. This standard contains criteria for design for road safety (e.g. set-back from the carriageway edge, kerbs and guardrails and poles to have frangible bases). The standard fails to define performance requirements for frangible pole bases or the behaviour of the pole under impact. It fails to define limitations on pole deflection and vibration under dead load and wind load. However, performance criteria, including frangible bases, are given in Transit New Zealand standard specifications, as discussed previously (refer to 7.7).

Transit New Zealand's "Manual of Traffic Signs and Markings" defines the sizes of standard signs and requirements for their siting and mounting. Materials, methods of construction, and erection and serviceability of signs is specified to comply with either "NZS 5414: 1977, The Construction of Traffic Signs", or with the Road Safety Manufacturers Association "Standard for the Manufacture and Maintenance of Traffic Signs, Post and Fittings". It should be noted that Appendix B of the "Standard for the Manufacture and Maintenance of Traffic Signs, Posts and Fittings" is in error.

The Austroads Publication "Guide to Traffic Engineering Practice, Part 12, Roadway Lighting" provides guidance on light pole types and refers to AS 1798 for preferred pole dimensions, but does not define performance criteria for structural design.

9.13.2 Recommendations

Performance criteria for light poles for inclusion in a new Road Structures Design Manual should be adopted from Transit New Zealand standard specifications M/18P and M19. For the design of signs, referral to Transit New Zealand's "Manual of Traffic Signs and Markings" and "Standard for the Manufacture and Maintenance of Traffic Signs, Post and Fittings" should be included subject to Appendix B of the latter document being corrected.

9.14 Snow Avalanche Protection Structures

9.14.1 Documents Coverage

This topic is not included in either document.

9.14.2 Recommendation

Transit New Zealand should review their policy toward provision of avalanche protection. If provision of avalanche protection is adopted, then criteria need development for the performance of snow avalanche protection structures, and should be included in a new Road Structures Design Manual.

10. MATERIALS DESIGN

10.1 General

10.1.1 Background

There is a policy under Closer Economic Relations (CER) between New Zealand and Australia to harmonise national standards. It is understood that in the area of structural design, loadings codes will be harmonised first, followed by materials design standards. At the inaugural meeting of the joint Australia - New Zealand bridge code committee, it was agreed that duplication of relevant materials standards was to be avoided.

From a New Zealand perspective, it is considered that duplication of materials covered by national standards should be avoided for the following reasons:

- Minimisation of the effort required from the engineering community in revising standards and acquiring their acceptance by the Building Industry Authority for referencing by their Approved Documents. Developing and maintaining in an up-to-date duplicate materials codes is wasteful of New Zealand's resource of qualified specialists.
- Practising engineers in New Zealand, engaged in bridge design, generally will also be engaged in the design of other structures to the national standards. Thus, adoption of national standards can be expected to eliminate confusion that might arise through people applying different standards to work of a similar nature.

10.1.2 Recommendation

Where appropriate national materials design standards are available, it is generally recommended that Transit New Zealand's design manual adopt THEM. As necessary, the road structures manual should incorporate additional materials criteria, where not covered by the national materials codes.

10.2 Concrete

10.2.1 Documents Coverage

10.2.1.1 Bridge Manual and NZS 3101.

The Bridge Manual adopts NZS 3101 Concrete Structures Standard for the design in concrete. The coverage of this code is illustrated by its section titles:

- General (encompassing: scope, interpretation, design and construction review).
- Definitions.

- Limit state design requirements and material properties.
- General design requirements (encompassing: general principles and requirements for analysis and design, and additional design requirements for earthquake effects).
- Design for durability.
- Design for fire resistance.
- Reinforcement - details, anchorage and development.
- Flexure with or without axial load.
- Shear and torsion.
- Composite concrete flexural members.
- Beam - column joints.
- Walls.
- Diaphragms.
- Two-way slab systems.
- Foundation elements.
- Prestressed concrete.
- Seismic requirements for elements of limited ductility.
- Strength evaluation of existing structures.

NZS 3101 is a comprehensive limit state concrete design code and incorporates requirements specifically for bridges and for earthquake resistant design. A feature of this code is that its durability requirements are based on an assumed design life of 50 years, as discussed above (Section 6.4.2).

The Bridge Manual presents requirements extending or clarifying the application of NZS 3101, and also for design of deck slabs including empirical design based on assumed membrane action.

10.2.1.2 Austroads Code.

The Austroads Code devotes Section 5 to concrete design. Again principal section headings illustrate the code's coverage:

- Scope and general.
- Design requirements and procedures.
- Loads and load combinations for stability, strength and serviceability.
- Design for durability.
- Design for fire resistance.
- Design properties of materials.
- Methods of structural analysis.
- Design of beams for strength and serviceability.
- Design of slabs for strength and serviceability.

- Design of columns and tension members for strength and serviceability.
- Design of walls.
- Design of non-flexural members, end zones and bearing surfaces.
- Stress development and splicing of reinforcement and tendons.
- Joints, embedded items, fixings and connections.
- Plain concrete members.
- Material requirements.
- Testing of members and structures.

Appendices provide coverage of:

- Suspension reinforcement design procedures.
- End zones for prestressing anchorages.
- Composite concrete members design procedures.
- Standard precast prestressed concrete girder sections.
- Box girders.
- Beam stability during erection.

The Austroads Code Section 5 specifically does not have detail of rules for seismic design.

10.2.2 Discussion

As can be seen from a comparison of the contents of NZS 3101 and the Austroads Code Section 5, there is some marked differences in format and coverage between these documents. The lack of coverage of seismic design detailing in the Austroads Code Section 5 is a significant shortcoming in the suitability of this code for New Zealand application. An indepth comparison of criteria for detailed aspects of design has not been undertaken. However, from the broad review undertaken, there appear to be differences in criteria and formulae that would require evaluation and explanation before acceptance for New Zealand use is recommended. While the durability requirements of the Austroads Code are based on a 100 year life, they would also require evaluation for appropriateness to New Zealand conditions.

An area where the NZS 3101 might be improved is the incorporation of specific criteria for the evaluation of, and design for, bursting stresses at anchorage zones in prestressed concrete and at bearing surfaces.

In light of the developments currently occurring in the background to this study, as outlined above in 10.1.1, it is appropriate to also consider the Australian national concrete standard, AS 3600:1994. A review of the table of contents of AS 3600:1994 suggests that code to have a format and content midway between that of the Austroads Code Section 5 and NZS 3101.

10.2.3 Recommendations

The New Zealand national standard NZS 3101 should be retained as the basis for concrete design. A detailed review of the Austroads Code Section 5 is recommended to identify and evaluate aspects applicable to road structures design that are not so comprehensively covered by NZS 3101 (e.g. the detailing of prestressed concrete anchorage zones and bearing surfaces). Such aspects should be brought to the attention of the Standards New Zealand concrete code committee.

10.3 Steel and Composite Construction

10.3.1 Documents Coverage

The Bridge Manual adopts BS 5400: Part 3 "Code of Practice for Design of Steel Bridges" and BS 5400 Part 5 "Code of Practice for Design of Composite Bridges" for design of steel and composite bridges. These are codes which have been written specifically for bridge design and are internationally recognised. They provide comprehensive design requirements for steel bridges including requirements appropriate to the design of steel box girders and orthotropic steel decks.

The Austroads Code currently does not include a steel design section, though one is proposed and publication is believed to be imminent. A draft Austroads Railways of Australia Bridge Design Code: Section 6 "Steel and Composite Construction" is under consideration by the Standards Australian BD/90 committee for preparation of a national bridge code. This draft appears to be comprehensive and encompassing:

- Materials.
- General design requirements.
- Methods of structural analysis.
- Steel beams.
- Composite beams.
- Composite box girders.
- Transverse members and restraints.
- Members subject to axial tension.
- Members subject to axial compression.
- Members subject to combined action.
- Combined action.
- Connections.
- Fatigue.
- Brittle fracture.
- Steel and cast iron components for bridge bearings.
- Testing of structures or elements.
- Appendices.

A detailed review of this draft document has not been undertaken. Subsequent to completion of the review work for this project, this draft document has been finalised and published as Section 6 of the Australian Bridge Design Code.

10.3.2 Discussion

National standards exist for steel design. They are NZS 3404: 1992 "Steel Structures Standard" and AS 4100: 1990 "Steel Structures Standard". NZS 3404 states, "this standard, broadly speaking, incorporates the provisions for bare steel member design from AS 4100: 1990, Steel Structures Standard and the provisions for seismic and composite design from NZS 3404: Part 2: 1989 Steel Structures Code: Means of Compliance [With Part 1: New Zealand Amendments to AS 1250: 1981]." Thus in the national steel standards, a large degree of unification of requirements exists. A review of the contents, however, suggests that the NZS 3404 has moved ahead of AS 4100, providing, in particular, more extensive coverage of seismic design and coverage of design, of composite members and structures.

The foreword to NZS 3404 also states, " The Standard is now suitable for bridge design utilising steel or composite sections in conjunction with the Transit New Zealand Bridge Manual: Design and Evaluation (for road bridges) .... additional or more stringent provisions for some aspects of steel bridge design may still be required by the relevant authority. This Standard is not written for steel box girder bridge design, for which reference to an appropriate limit state Standard or design procedure is required."

A comparison of the Austroads - Railways of Australia draft document table of contents with that of NZS 3404, indicates a close alignment of topics, but with significant additional sections in to the former document for:

- Composite beams.
- Composite box girders.
- Transverse members and restraints.
- Capacity of composite compression members.
- Steel and cast iron components for bridge bearings.

There are variations between the documents in the presentation (and possibly the contents) of sections dealing with materials and brittle fracture. Requirements for fire and seismic design do not appear in the Austroads - Railways of Australia document and sections on fabrication, erection, and modification of existing structures have been moved to appendices and possibly vary.

Revision of NZS 3404 is currently in progress with the draft available for public comment. The draft has not been reviewed within this project.

10.3.3 Recommendations

A detailed review of the revised NZS 3404 document, when it is finalised, and the Australian Bridge Design Code Section 6 is recommended. This review should encompass the adequacy of the documents' requirements for steel design for structures encountered in the New Zealand roading environment as compared to continued use of BS 5400 Parts 3 and 5. Consideration should then be given to the practicality of adopting of the revised NZS 3404, with coverage from the Australian Bridge Design Code, for areas not in the revised NZS 3404, to be incorporated into the steel design section of Transit New Zealand's design manual.

Retention of the BS 5400:Parts 3 and 5 may still be necessary for structures of forms not commonly encountered, e.g. for orthotropic steel decks, but adoption of the national standard for common structural forms is favoured if evaluation shows it to be adequate.

10.4 Timber (TNZ BM Cl. 4.4)

10.4.1 Documents Coverage

The Bridge Manual requires the use of the working stress method in accordance with NZS 3603: 1990 Code of Practice for Timber Design.

The Austroads Code does not contain requirements for design in timber.

10.4.2 Discussion and Recommendations

The present Bridge Manual requirements are out of date and not consistent with adoption of a limit state philosophy for design. NZS 3603: 1990 has been superseded as a national standard by NZS 3603:1993 Timber Structures Standard, which presents timber design in a limit states format. This standard should be reviewed and considered for adoption.

10.5 Aluminium

10.5.1 Documents Coverage

The Bridge Manual requires design to be in accordance with AS 1664 Rules for the use of Aluminium in Structures, alternatively known as the SAA Aluminium Structures Code.

The Austroads Code does not contain requirements for design in aluminium.

10.5.2 Discussion and Recommendations

AS 1664 is a working stress design code, inconsistent with the adoption of a limit state design philosophy, however it is currently under revision to be published as a limit state code and joint Australian / New Zealand standard. The British Standards Institution has produced a limit state code, BS 8118:1991, for design in aluminium. Aluminium is not known to have been used in New Zealand for the design of main bridge members, but is commonly used for pedestrian barriers. Therefore provisions for design in aluminium should be retained. Until there is an acceptable limit state standard for design in aluminium, an alternative formulation of load cases for working stress design will need to be retained in Transit New Zealand's design manual. Either BS 8118 or the revised AS 1664, when available, as limit state codes, should be reviewed for adoption.

10.6 Other Materials (TNZ BM Cl. 4.6)

10.6.1 Documents Coverage

Criteria applying to the use of materials not mentioned in the Bridge Manual require the approval of the General Manager, Transit New Zealand.

The Austroads Code does not contain any criteria in respect to use of other materials.

10.6.2 Recommendations

The present requirement should be retained.

11. EARTHQUAKE RESISTANT DESIGN

11.1 Philosophy and Analysis and Design Criteria (TNZ BM Section 5 and NZS 3101, Austroads Code Cl. 2.13 & 5.1.1.2)

11.1.1 Documents Coverage

The Bridge Manual devotes a whole section, (Section 5), to earthquake resistant design. Earthquake resistant design is a generally dominant aspect in the design of structures in New Zealand. Section 5 provides comprehensive coverage, encompassing the following:

- Design philosophy;
- Categorisation of structural action;
- Design earthquake loading and ductility demand;
- Methods of analysis;
- Member and foundation design criteria;
- Structure integrity and provisions for relative displacement; and
- Earth retaining structures.

NZS 3101, the concrete materials design code adopted by the Bridge Manual, includes comprehensive requirements for the design of concrete structures for earthquake resistance. For the earthquake resistant design of steel structures, the Bridge Manual requires compliance with Section 12 Seismic Design of NZS 3404: 1992 Steel Structures Standard.

The Austroads Code, apart from specifying design loading, provides only a minimum of general criteria for earthquake resistant design (Cl. 2.13.2). These require the structural system characteristics, site seismicity and dynamic response of the structure to be considered. The design is required to provide sufficient stability for the structure as a whole and for the components, with particular attention given to prevention of the superstructure from becoming dislodged from its supports. Dynamic analyses are required for "special structures" such as bridges with long periods of resonant vibration, bridges which have substructures of tall slender proportions, and bridges which have large variations in support stiffness.

Section 5 of the Austroads Code, Concrete, states that it "does not cover detail rules for seismic design. Where design for seismic disturbances is required as set out in Section 2, reference to specialist literature should be made."

11.1.2 Recommendations

The Bridge Manual criteria for earthquake resistant design should be retained. The design seismic hazard spectra should be reviewed for consistency with the adopted ultimate limit state level of performance required, as discussed previously under Design Loadings. In a new ideal road structures design manual, the present presentation should be reviewed for appropriateness consistent with the adopted ordering and grouping of criteria and other material into sections.

12. LIGHTLY TRAFFICKED RURAL BRIDGES

12.1 Design Criteria (TNZ BM Appendix D)

12.1.1 Documents Coverage

The Bridge Manual presents design criteria for lightly trafficked rural bridges in an appendix. These criteria relate to one lane bridges on public or private roads. On public roads these criteria may be applied where:

- The vehicle count is less than 100 per day;
- The road cannot become a through route;
- The alignment is such that speeds are generally below 70 km/hour;
- Use of the route by logging trucks is unlikely; and
- No significant overloads are expected to occur, or the bridge can be bypassed.

The design criteria allow reduced standards of width and side protection, reduced traffic design load (0.85HN only), and design load combinations with higher permissible working stresses or reduced load factors, compared to the criteria generally applied to other road bridges.

The Austroads Code does not present criteria for lightly trafficked rural bridges as such, but does introduce a concept of service levels as discussed previously. Though not always referred to as service levels, different design loadings are adopted for routes of different classification, and geometric and side protection requirements also vary according to circumstances. Service availability under flood conditions might also vary, depending on bridge authority requirements.

12.1.2 Discussion and Recommendations

Transit New Zealand have had a policy of eliminating differences in the design strength of bridges, on the basis that trucks can travel anywhere and it is impractical to police and control where they go. Class 2 routes have been phased out. However, a study is currently in progress to examine the net benefits of increasing vehicle weight and configuration standards. If adopted, the practicalities of implementation are likely to result in a phased introduction in which selected routes are upgraded ahead of others.

The policy issue of classification of routes and roads in terms of service level, to which different levels of performance (service availability under flood conditions, acceptable damage from earthquake, geometric standards, etc.) are assigned, should be considered and evaluated for the economic benefits that could arise. This has widespread implications for the Transit New Zealand ideal manual and how its requirements are developed and expressed.

Retention of the existing Bridge Manual criteria for lightly trafficked rural bridges is recommended. This could correspond to the lowest of several defined service levels.

13. STRUCTURE CAPACITY EVALUATION

13.1 Criteria for Structure Capacity Evaluation

13.1.1 Documents Coverage (TNZ BM Section 6)

The Bridge Manual devotes a whole section (Section 6) to the evaluation of existing bridges and culverts. This section is written to provide the structural information required for operating of Transit New Zealand's overload permit system and the procedures for imposing load restriction on bridges of substandard capacity. This section encompasses:

- the objective;
- rating and posting requirements; and
- evaluation procedures.

The overload rating and for posting evaluation procedures cater for both main elements and deck slabs . They encompass:

- Vehicle loading impact factors;
- Material strengths;
- Evaluation of section capacity; and
- Proof loading.

The Austroads Code does not contain criteria specifically for the capacity evaluation of structures. The Austroads publication "Bridge Management Practice" provides a general description of the capacity evaluation and of the factors to be considered. Requirements for bridge rating have been developed jointly by Austroads and Railways of Australia which were in draft form and received only on a confidential basis at the time of the review work of this project. These requirements have been subsequently finalised and published as Section 7 of the Australian Bridge Design Code.

13.1.2 Recommendations

The Bridge Manual criteria for evaluation of the capacity of existing structures should be retained. As load factors and load combinations for design are reviewed and revised in the design manual to be consistent with the adopted ultimate limit state design basis. They should also be reviewed and revised as appropriate within the criteria for structure capacity evaluation.

PART C: PROJECT OVERALL CONCLUSIONS

14. CONCLUSIONS

A framework has been developed to provide a context within which to define the scope of the ideal design document to be considered by this project. From that, it was resolved with Transit New Zealand that the document to be considered would be an ideal road structures design manual. Topics requiring coverage, set out as a framework for the manual, and criteria to be met in the presentation format and content of the manual are summarised below.

While the focus of this project has been on comparing the Bridge Manual and Austroads Code, it is clear that attainment of an ideal road structures design manual would entail a merging and significant modification of both documents, rather than adoption of one or the other. There are other sources of information and other approaches which should be considered in formulating an ideal manual for use in New Zealand or for joint use in New Zealand and Australia. Within the English speaking countries, examples of such codes which are widely accepted include the British BS 5400 and the Ontario and the AASHTO codes. The Eurocode should also be considered when available.

In the interim the Bridge Manual should be retained and maintained. The Austroads Code is not considered suitable for adoption by Transit New Zealand in its present state due to the factors outlined in the following sections.

14.1 Ideal Road Structures Manual Topic Coverage

In a new Transit New Zealand ideal road structures design manual, topics requiring coverage include the following:

- Code applicability and scope;
- Design objectives and philosophy and basis;
- Project initiation and approval;
- Site information;
- General design criteria;
- Design loadings;
- Analysis criteria;
- Criteria for materials design;
- Criteria for structural elements design;
- Earthquake resistant design;
- Criteria for lightly trafficked rural bridges;
- Acceptable solutions for elements for which compliance with the specified performance criteria may be too onerous to demonstrate;
- Structure capacity evaluation.

14.2 Ideal Road Structures Design Manual Criteria to be met

A new Transit New Zealand ideal road structures design manual should satisfy the following criteria and that it should:

- Be expressed in limit state format;
- Be expressed in terms of performance wherever possible;
- Specify design loadings and load combinations derived on a basis of harmonisation of the design life with Transit New Zealand's risk policy with respect to their structures' exposure to hazards;
- Be expressed in nomenclature that is consistent with other reference codes and documents, in particular with that used by Standards New Zealand;
- Adopt New Zealand national standards for loadings and materials design where they are appropriate and available;
- Be compatible with the New Zealand Building Act, and, with the exception of any disclaimer contained, be acceptable to the BIA for referencing by the approved documents for the intended range of application;
- Include "means of compliance" acceptable solutions for aspects of performance based design criteria for which compliance may be onerous to demonstrate; and
- Be published in a format enabling amendment with minimal effort, preferrably similar to that adopted by the present bridge manual.

14.3 Specificity and Performance Based

The Bridge Manual is written to set out comprehensively the requirements of Transit New Zealand and wherever possible is expressed in terms of required performance. By comparison, a feature of the Austroads Code is that it is written to cater for the diverse needs of State roading authorities spread over a continent. As a consequence, in a number of areas it lacks specificity, providing only broad requirements or guidelines, and refers the user to the State roading authority for their particular requirements. In parts it is prescriptive, providing design methods and design guidance, which is not compatible with the policy applied by Transit New Zealand to its bridge design manual.

14.4 Applicability and Scope

In a new Transit New Zealand manual the scope should be expanded beyond that of both the Bridge Manual and the Austroads Code to encompass the geometric and structural design of all roading structures. Additional structures that should be included, either directly or by positive referral to other design standards, include corrugated metal plate culverts, pedestrian facilities (e.g. subways and access ramps and stairs to subways and bridges), lighting poles, signs and sign gantries, retaining walls and ground anchors, and avalanche protection structures.

14.5 Limit State Philosophy and Approach

The Austroads Code is generally more up to date and consistent than the Bridge Manual in its expression in limit state terms. It introduces the concept of levels of service for some aspects of design, which merits further development and wider application. Consideration should be given, in revising the Bridge Manual or developing an ideal manual, to the basis adopted for the ultimate limit state, principally, whether it is appropriate to apply the same design life and level of risk to all structures. Fundamental to the development and confirmation of other criteria, is the establishment or confirmation of the limit state basis to be adopted. This should set out the design lives required, levels of risk (probabilities of event exceedance) acceptable, and levels of service required. Resolution of this issue is a high priority.

14.6 Design Traffic Loadings

Design traffic loadings are a major issue to be considered in seeking to harmonise with Australian practice. There are significant differences between loadings adopted by the Bridge Manual and those adopted by the Austroads Code. The design traffic loadings need to reflect the heavy transport vehicle regulations of the country, and in the future development. Changes to design traffic loadings and heavy traffic vehicle regulations will have repercussions for the administration of the overload permit system and to the posting of bridges with substandard load capacity. This topic within the design manual should not be viewed in isolation, but should take into account future trends and other current Transit New Zealand research on increasing the legal vehicle weights and configurations.

14.7 Earthquake Resistant Design

Earthquake resistance is a dominant aspect of design for many structures, and especially so for bridges in New Zealand. This aspect is covered comprehensively by the Bridge Manual but receives only minimal and incomplete coverage in the Austroads Code.

14.8 Capacity Evaluation of Existing Structures

Capacity evaluation of existing structures is a significant topic, covered by the Bridge Manual but currently not included in the Austroads Code. It is an essential topic to be included in any new design manual or code adopted by Transit New Zealand.

14.9 Materials Design Criteria

Materials design standards are currently included or intended to be included within the Austroads Code, whereas the Bridge Manual adopts appropriate national or international standards and incorporates additional criteria where necessary. Adoption of national standards is to be preferred wherever possible, thereby minimising the resources required in maintaining "state-of-the-art" design standards and designers familiar with them.

REFERENCES

Austroads, 1992, *'92Austroads Bridge Design Code,* Austroads, Sydney.

Austroads, 1991, *Bridge Management Practice,* Austroads, Sydney.

Austroads, 1994, *Waterway Design: A Guide to Hydraulic Design of Bridges, Culverts and Floodways,* Austroads, Sydney.

Austroads, 1988, *Guide to Traffic Engineering, Part 12, Roadway Lighting,* Austroads Publication AP 11.12/88, (previously National Association of Australian State Road Authorities), Sydney.

Austroads, Australasian Railways Association, Standards Australia, 1996, *Australian Bridge Design Code, Section 6 - Steel & Composite Construction, Section 7 - Rating,* Austroads, Sydney.

British Standards Institute, 1978, *BS 5400: Part 2: 1978, Steel, Concrete and Composite Bridges, Part 2. Specification for Loads,* British Standards Institute, London.

British Standards Institute, 1982, *BS 5400: Part 3: 1982, Steel, Concrete and Composite Bridges, Part 3. Code of practice for design of steel bridges,* British Standards Institute, London.

British Standards Institute, 1979, *BS 5400: Part 5: 1979, Steel, Concrete and Composite Bridges, Part 5. Code of practice for design of composite bridges,* British Standards Institute, London.

British Standards Institute, 1983, *BS 5400: Section 9.1: 1983, Steel, Concrete and Composite Bridges, Part 9. Bridge bearings, Section 9.1 Code of practice for design of bridge bearings,* British Standards Institute, London.

British Standards Institute, 1983, *BS 5400: Section 9.2: 1983, Steel, Concrete and Composite Bridges, Part 9. Bridge bearings, Section 9.2 Specification for materials, manufacture and installation of bridge bearings,* British Standards Institute, London.

British Standards Institute, 1980, *BS 5400: Part 10: 1980, Steel, Concrete and Composite Bridges, Part 10. Code of practice for fatigue,* British Standards Institute, London.

British Standards Institute, 1991, *BS 8118: 1991, Structural Use of Aluminium, Part 1: Code of practice for design,* British Standards Institute, London.

British Standards Institute, 1991, *BS 8118: 1991, Structural Use of Aluminium, Part 2: Specification for materials, workmanship and protection,* British Standards Institute, London.

Building Industry Authority, 1992, *The New Zealand Building Code Handbook and Approved Documents,* Standards New Zealand, Wellington.

Department of the Environment, 1976, *BE 1/76, Design Requirements for Elastomeric Bridge Bearings,* Technical Memorandum (Bridges), United Kingdom Department of the Environment, Highway Directorate

National Roads Board Urban Transport Council, 1985, *Guide to Cycle Facilities,* National Roads Board, Wellington.

Standards Australia, 1986, *AS 1158.1: 1986 Code of Practice for Public Lighting: Performance and installation design requirements* , Standards Australia, Sydney.

Standards Australia, 1981, *AS 1523: 1981 Elastomeric Bearings for Use in Structures,* Standards Australia, Sydney.

Standards Australia, 1979, *AS 1664: 1979 Rules for the Use of Aluminium in Structures,* Standards Australia, Sydney

Standards Australia, 1990, *AS 4100: 1990, Steel Structures Standard,* Standards Australia, Sydney.

Standards New Zealand, 1995, *NZS 3101:1995 Concrete Structures Standard,* (Part 1 - The Design of Concrete Structures, and Part 2 - Commentary on the Design of Concrete Structures), Standards New Zealand, Wellington.

Standards New Zealand, 1992, *NZS 3404: 1992 Steel Structures Standard,* Standards New Zealand, Wellington.

Standards New Zealand, 1990, *NZS 3603: 1990 Code of Practice for Timber Design,* Standards New Zealand, Wellington.

Standards New Zealand, 1993, *NZS 3603: 1993 Timber Structures Standard,* Standards New Zealand, Wellington.

Standards New Zealand, 1992, *NZS 4203:1992 Code of Practice for General Structural Design and Design Loadings for Buildings,* (Vol 1 Code of Practice, Vol 2 Commentary), Standards New Zealand, Wellington.

Standards New Zealand, 1983, *NZS 6701: 1983 Code of Practice for Road Lighting,* Standards New Zealand, Wellington.

Transit New Zealand, 1994, *Bridge Manual,* Transit New Zealand, Wellington.

Transit New Zealand, 1995, *Manual of Traffic Signs and Markings, Part 1: Traffic Signs,* Transit New Zealand, Wellington.

Transit New Zealand, 1994, *Management of Road Traffic Noise - State Highway Improvements, (Draft Guidelines),* Transit New Zealand, Wellington.

Transit New Zealand and Road Safety Manufacturers Association, 1995, *Standard for the Manufacture and Maintenance of Traffic Signs, Posts and Fittings,* Road Safety Manufacturers Association.

Transit New Zealand, 1990, *TNZ M/18P:1990 Specification for Fibreglass Reinforced Plastic Highway Lighting Columns,* Transit New Zealand, Wellington.

Transit New Zealand, 1994, *TNZ M/19: 1994 Specification for Tubular Steel Lighting Column,* Transit New Zealand, Wellington.