Review of Australian standard AS5100 Bridge design with a view to adoption - Volume 1
October 2008

Research Report 361

Review of Australian standard AS 5100 Bridge design with a view to adoption

Volume 1

D. K. Kirkcaldie
Opus International Consultants Limited
Wellington

J. H. Wood
John Wood Consulting
Lower Hutt

NZ Transport Agency Research Report 361

ISBN 978-0-478-33423-4
ISSN 1173-3756

Private Bag 6995, Wellington 6141, New Zealand
Telephone 64 4 894 5400; Facsimile 64 4 894 6100
Email: research@nzta.govt.nz
Website: www.nzta.govt.nz

Kirkcaldie, D. K., and Wood, J. H. 2008. Review of Australian standard AS 5100 Bridge design with a view to adoption. Volume 1. *NZ Transport Agency Research Report 361.* 130 pp.

This report is published in two volumes as follows:

Volume 1: Executive summary, recommendations and parts 1 to 4
Volume 2: Parts 5 to 8

Keywords: AS 5100, Australian bridge design, Transit NZ *Bridge manual*

An important note for the reader

The NZ Transport Agency is a Crown entity established under the Land Transport Management Act 2003. The objective of the NZ Transport Agency is to undertake its functions in a way that contributes to an affordable, integrated, safe, responsive, and sustainable land transport system. Each year, the NZ Transport Agency invests a portion of its funds on research that contributes to this objective.

This report is the final stage of a project commissioned by Land Transport New Zealand before 31 July 2008 and is published by the NZ Transport Agency.

Additional note

The NZ Transport Agency (NZTA) was formally established on 1 August 2008, combining the functions and expertise of Land Transport NZ and Transit NZ.

The new organisation will provide an integrated approach to transport planning, funding and delivery.

This research report was prepared prior to the establishment of the NZTA and may refer to Land Transport NZ and Transit NZ.

Acknowledgments

The authors would like to acknowledge the contributions made to this project by the peer reviewers: Howard Chapman and Ian Billings, and the project steering group: Frank McGuire (formerly Transit New Zealand), Ron Muir (Hutt City Council), Charles Clifton (University of Auckland), and Ross Cato (Precast NZ).

Abbreviations and acronyms

AADT	Annual average daily traffic
AASHTO	American Association of State Highway and Transportation Officials
ACI	American Concrete Institute
AS	Australian standard
AS 5100	AS 5100:2004. Bridge design
ASTM	American Society for Testing and Materials
Bridge manual	*Bridge manual*, 2nd edition 2003 and amendments, Transit New Zealand
BS	British standard
BSI	British Standards Institute
HERA	Heavy Engineering Research Association
HLP	Heavy load platform
NZBC	New Zealand Building Code
NZS	New Zealand standard
NZTA	New Zealand Transport Agency
SAI	SAI Global Ltd
SLS	Serviceability limit state
TOPS	Transit New Zealand's Overweight Permit System
Transit	Transit New Zealand (now NZ Transport Agency)
Transit NZ	Transit New Zealand (now NZ Transport Agency)
UDL	Uniformly distributed load
ULS	Ultimate limit state

Contents: Volume 1

Executive summary

The objective of this project was to investigate the suitability and practicality of adopting the Australian standard AS 5100:2004 (AS 5100) for bridge design for New Zealand. To complete this objective, the significant differences and gaps between current design requirements of AS 5100 and the Transit NZ *Bridge manual* (2nd ed 2003) and its supporting standards were identified. The project considered the New Zealand regulatory environment and identified the measures required to enable the use of AS 5100 in New Zealand.

Each section of the seven parts of AS 5100 was compared with the equivalent section of the *Bridge manual* and its supporting standards. A summary is given below of the main differences between the two design documents and the material needed in terms of supplementary documents to make AS 5100 suitable for application to bridge design in New Zealand. The full extent of the material that would need to be harmonised is considerable. See the appropriate sections in the report for a more complete identification of the supplementary material required if AS 5100 were adopted. Following the conclusions given below, tables E1 to E6 summarise the actions required for the preparation of supplementary documentation necessary to make parts 1, 2, 3, 5 and 6 of AS 5100 suitable for adoption in New Zealand. Part 4 of AS 5100 'Bearings and deck joints' has already been adopted by the *Bridge manual* and if AS 5100 were adopted it is recommended that part 7 'Rating of existing bridges' be adopted in its entirety (with minor supplementary material) as a guideline document together with the present *Bridge manual* section 6 'Evaluation of bridges and culverts'.

The parts and sections in AS 5100 are referred to below using the numbering in the standard.

AS 5100.1: Scope and general principles

Sections 1 and 2: Scope and application

The scope and application sections of AS 5100.1 encompass the scope and application of the *Bridge manual* and could be adopted without significant change.

Section 3: Referenced documents

Additions and some exclusions would need to be made to the AS 5100.1 section 3 list of referenced documents to incorporate relevant New Zealand standards and regulations.

Section 4: Definitions

AS 5100.1 and AS/NZS 1170 definitions of design life and design working life are consistent with the durability requirements of the *Bridge manual*. However, the *Bridge manual* provides the more appropriate definition of design working life and also treats durability explicitly, which is the preferred approach.

Section 5: Notation

Section 5 of AS 5100.1 is suitable for adoption without modification, subject to the clauses to which the notation refers being adopted without modification.

Section 6: Design philosophy

Section 6 of AS 5100.1 is generally suitable for application in New Zealand; however, if AS 5100 were adopted, its philosophy would need to be checked with the Department of Building and Housing to ensure it meets the requirements of the New Zealand Building Code (NZBC). In view of the philosophical differences between AS 5100.1 and the *Bridge manual*, supplementary documentation may be required to address the following:

- the specification of design lives for ancillary structures
- the replacement of the definition of ultimate actions with *Bridge manual* text describing the basis of derivation of design ultimate actions as applied in New Zealand
- the incorporation of specific requirements for durability and structural robustness corresponding to those set out in the *Bridge manual*.

Section 7: Waterways and flood design

Section 7 of AS 5100.1 sets out general waterway and flood design considerations, which are suitable for application in New Zealand when supplemented by the specific requirements of the *Bridge manual*, and with the design flood events replaced by the *Bridge manual* requirements.

Section 8: Environmental impact

AS 5100.1 section 8 requirements are appropriate for adoption for New Zealand use.

Section 9: Geometric requirements

Section 9 of AS 5100.1 outlines the factors to be considered in determining geometrics of the bridge deck cross-section but in some respects it is less specific than the *Bridge manual* for the make-up of the deck cross-section and the various combinations of lane width, edge clearance, barrier form and footpaths/cycletrack. Before adopting AS 5100.1 bridge width criteria, Transit's roading geometrics and traffic safety specialists would need to review them in detail.

The AS 5100.1 approach of adopting different vertical clearances dependent on the road type being crossed would need to be modified for application in New Zealand.

AS 5100.1 geometric provisions for footbridges, subways and cyclepaths are generally appropriate for New Zealand, but a review of the width necessary to accommodate cyclists on the road carriageway would be required as the provisions are wider than the 1.5 m shoulders usually provided in New Zealand.

Section 10: Road traffic barriers

AS 5100.1 section 10 criteria are generally suitable for adoption in New Zealand except that NCHRP 350 test level 3 (TL3) is a more appropriate lower bound for the minimum level of side protection.

If AS 5100.1 were adopted, it would be desirable to prepare supplementary documentation retaining:

- the *Bridge manual*'s risk-based procedure for derivation of the required performance level
- the listing of preferred acceptable non-proprietary barrier solutions
- Transit's requirements for geometric layout, end treatment and transitions

- the drawings of standard detailing for the Transit W-section bridge guardrail system.

Section 11: Collision protection

AS 5100.1 section 11 requirements for collision protection are suitable for application in New Zealand.

Section 12: Cycle path barriers

AS 5100.1 section 12 requirements for pedestrian and bicycle-path barriers are generally suitable for application in New Zealand. Supplementary documentation would be required to cover requirements for kerbs.

Section 13: Noise barriers

AS 5100.1 section 13 requirements for noise barriers are suitable for application in New Zealand. However, they are not very extensive and it would be necessary to consider whether they are sufficiently comprehensive.

Section 14: Drainage

AS 5100.1 section 14 requirements are suitable for adoption in New Zealand. However, the *Bridge manual* provisions largely complement these requirements with little duplication and if AS 5100.1 were adopted the provisions should be retained and included in supplementary documentation.

Section 15: Access for inspection and maintenance

AS 5100.1 section 15 requirements are suitable for adoption in New Zealand.

Section 16: Utilities

AS 5100.1 section 16 requirements are suitable for adoption in New Zealand. However, the *Bridge manual* provisions largely complement these requirements and if AS 5100.1 were adopted the provisions should be retained and included in supplementary documentation.

Appendix A: Matters for resolution before design commences

The adoption of AS 5100.1 would require a review of all appendix A clauses. Transit's requirements for each would need to be included in supplementary documentation.

Appendix B: Road barrier performance level selection method

Overall, the AS 5100.1 appendix B road barrier performance selection method is suitable for application in New Zealand and offers some improvements over the current *Bridge manual* method. The adoption of AS 5100.1 would require a review of the appropriateness of the road type and curvature factors for New Zealand conditions. If the current *Bridge manual* factors were retained, supplementary documentation would need to be prepared. Retention of the *Bridge manual* criteria for performance levels 6 and special would need to be considered.

AS 5100.2: Design loads

Section 1: Scope and general

Section 1 of AS 5100.2 is suitable for application in New Zealand, but would benefit from having the list of information to be presented on the drawings extended to include:

- foundation bearing capacity

- material characteristic strength and properties (eg concrete compressive strength f'_c, steel yield strength f_y) and the steel material standard .

Section 2: Referenced documents

If AS 5100.2 were adopted, additions and possibly some exclusions would need to be made to the section 2 reference list to incorporate documents relevant to New Zealand.

Section 3: Definitions

Section 3 of AS 5100.2 states that the definitions of AS 5100.1 apply. See comments made for AS 5100.1.

Section 4: Notation

Section 4 of AS 5100.2 is suitable for adoption without modification subject to the clauses to which the notation refers being adopted without modification.

Section 5: Dead loads

AS 5100.2 section 5 dead load ultimate limit state (ULS) load factors are significantly lower than those adopted by the *Bridge manual*, while the superimposed live load ULS factors are significantly higher. The *Bridge manual* load factors for dead load generally align reasonably with AS/NZS 1170.

Before AS 5100.2 could be adopted a detailed review of load factors and load combinations appropriate for New Zealand should be carried out. This review would need to extend to all other load types to ensure alignment with the safety index adopted by the NZBC and its supporting verification methods and approved documents.

If AS 5100.2 were adopted it would also be necessary to improve the treatment of load factors and strength reduction factors for soil retaining structures. This area is not adequately covered in the *Bridge manual*.

Section 6: Road traffic

Except at span lengths approaching 100 m, the moving load model (M1600) is the dominant design loading specified in AS 5100.2 section 6 and is approximately twice the design loading currently adopted in New Zealand for spans over 20 m. The AS 5100.2, A160 axle loading is 1.33 times higher than the *Bridge manual* HN axle loading. Adoption of the AS 5100.2 design traffic live loading would have significant implications for the construction cost of new bridges and require the development of policy for the management of the load capacity of existing bridges.

The AS 5100.2, M1600 and stationary load model (S1600) design loadings, with their unsymmetrical arrangement of varying and variable axle group spacings, are unnecessarily complicated simulations of design loading that would add considerably to the modelling and analysis effort involved in design. The *Bridge manual* HN and HO loadings are much simpler and give a satisfactory representation of the traffic load effects on New Zealand bridges. The AS 5100 approach of applying reduction factors for multiple lanes loaded to individual lanes is similarly more complicated than the *Bridge manual* approach, and again the justification for this added complexity is questionable.

A review was recently undertaken of the design traffic live loadings appropriate for use in New Zealand and, as a result, revisions were made. However, these revisions are currently subject to debate between NZ Transport Agency (NZTA) and other parties and it would not be appropriate to adopt the AS 5100.2 design traffic live loads at the present time.

Section 7: Pedestrian and bicycle-path load

The AS 5100.2 section 7 footpath uniformly distributed load (UDL) generally reduces more rapidly in relation to length than the *Bridge manual* loading. Which load specification is more appropriate is not clear and would require a more detailed review if AS 5100.2 were adopted.

The AS 5100.2 specification for accidental loading of a footpath by a vehicle, at one-third the rate set out in the *Bridge manual*, is not suitable for adoption. The AS 5100.2 service access loading is also judged to be too light, equating to approximately two to three people.

Section 9: Minimum lateral restraint capacity

The AS 5100.2 section 9 requirement for the provision of lateral force capacity at each continuous section of the bridge superstructure could be adopted, but the level of restraint should be revised to have a more rational basis.

Section 10: Collision loads

AS 5100.2 section 10 and the *Bridge manual* design loads and method of application for traffic collision with bridge supports are essentially the same. The *Bridge manual* provisions for train collision were adopted from the 1992 Austroads bridge design code, and so bear some similarity to the AS 5100.2 requirements but these have now been extensively revised and extended. The *Bridge manual* covers possible ship impact on bridge piers but this load is not covered in AS 5100.2.

If AS 5100.2 collision load requirements were to be adopted supplementary documentation would be needed to:

- clarify the circumstances for which the design of traffic collision load on supports would be required
- incorporate a design traffic collision loading for bridge superstructures
- clarify, for train collisions and the alternative load path approach, when more than one pier is considered to be removed
- present alternative requirements regarding train collision when not based on pier support redundancy
- incorporate requirements for withstanding possible ship impact.

Section 11: Kerb and barrier design loads and other requirements for road traffic bridges

AS 5100.2 section 11 requirements for kerb and barrier design loads do not adequately reflect the requirements of the *Bridge manual*. If AS 5100.2 were to be adopted, detailed review of some aspects and supplementary documentation would be required in the following areas:

- The *Bridge manual* barrier acceptance criteria would need incorporation.
- Barrier design loads for performance level 3 traffic barriers would need incorporation.
- The traffic barrier failure hierarchy would require review.
- The AS 5100.2 requirement prohibiting shear keying between the abutting ends of adjacent parapets at expansion joints would require revision.

- The design loads for pedestrian barriers would require detailed review, in view of the significant differences between the AS 5100.2 and *Bridge manual* design loadings.
- The design loadings for handrails mounted on top of traffic barriers would need review and incorporation.

Section 12: Dynamic behaviour

For road bridges, AS 5100.2 section 12 offers an attractively simple initial approach for dynamic loading; however, it is based on the AS 5100.2 design traffic live loading. For pedestrian bridges, the AS 5100.2 load of 700 N appears to be unrealistically high, as the 'dynamic excitation' load and a person's speed of travel across the bridge is not well defined. By comparison, the BS 5400 part 2 loading adopted by the *Bridge manual*, applies a sinusoidally varying load with a peak magnitude of 180 N, which appears more reasonable.

To adopt the AS 5100.2 provisions for dynamic behaviour, review and supplementary documentation would be required to consider the:

- specification of the design loadings for road bridges
- specification of the dynamic behaviour acceptance criteria for road bridges for at least those requiring dynamic analysis
- clarification of the speed of travel of the design load for pedestrian bridges.

Section 13: Earth pressure

The AS 5100.2 section 13 surcharge load is designed to be a simulation of the design traffic load effects on retaining walls. If the AS 5100.2 design traffic loads were not adopted, and the HN-HO loading retained, then the *Bridge manual* earth pressures from traffic live loading should also be retained.

AS 5100.2 section 13 provides an appropriate method for simulation of the effects of train loading on earth retaining structures.

Section 14: Earthquake forces

AS 5100.2 section 13 requirements do not incorporate seismic hazard spectra for New Zealand or provide the necessary depth of treatment for such a dominant aspect of structural design in New Zealand. If AS 5100.2 were adopted, extensive supplementary documentation would be required to largely replace this section and incorporate seismic resistant design criteria appropriate to New Zealand.

Although the AS 5100.2 earthquake load provisions could perhaps be adopted for low seismicity areas in New Zealand, a consistent approach for all of New Zealand seems necessary to ensure acceptability of designs for building consent under the New Zealand Building Act 2004.

Section 15: Forces resulting from water flow

The AS 5100.2 section 15 provisions for forces resulting from water flow are generally more comprehensive than those presented in the *Bridge manual*, and could be adopted with minor changes to clarify lift factors for small angles of attack on piers and the shape and size for the design debris raft.

If AS 5100.2 were adopted, supplementary documentation would be required to incorporate the minor changes for lift factors and angles of attack and to retain the *Bridge manual* ULS and SLS design return periods which align with AS/NZS 1170.

Section 16: Wind loads

The *Bridge manual* adopts the BS 5400 part 2 approach which requires consideration of wind acting on adverse and relieving areas, and reduces the design wind speed for wind acting on relieving areas. The BS 5400 Part 2 and AS 5100.2 section 16 approaches have a lot of similarity in their derivation of drag and lift coefficients and loaded areas, but the BS 5400 approach is generally a little more refined than the provisions of AS 5100.2.

If AS 5100.2 were adopted, the *Bridge manual* requirements for wind load should be retained as they are more comprehensive than those presented in AS 5100.2 and the return periods for the ULS and SLS align with AS/NZS 1170.

Section 17: Thermal effects

The AS 5100.2 section 17 treatment of overall temperature effects is geared to Australian conditions and is not directly applicable to New Zealand.

For differential temperature, a detailed study is needed to compare the results from applying the AS 5100.2 differential temperature gradient curves with those given in the *Bridge manual*.

If AS 5100 were adopted, supplementary documentation would be required to incorporate temperature ranges for overall temperature change effects and reference temperature gradients appropriate for New Zealand conditions and for the bridge types used in New Zealand.

Section 18: Shrinkage, creep and prestress effects

While the requirements of AS 5100.2 section 18 are generally suitable for adoption, they would need to be extended, through supplementary documentation, to incorporate additional requirements given in the *Bridge manual* on the use of cracked sections, restraint of bearings and differential shrinkage in composite structures. In addition, a review of the load factors adopted by AS 5100.2 would be required.

Section 19: Differential movement of supports

The AS 5100.2 section 19 requirements for differential movement are generally suitable for adoption but if adopted supplementary documentation would be required to cover:

- differential settlement as an ULS load condition
- extended causes of ground deformation
- horizontal and rotational deformations imposed on the structure.

Section 20: Forces from bearings

AS 5100.2 section 20 requirements are generally suitable for adoption but the treatment of bearing frictional forces at the ULS should be more clearly expressed.

Section 21: Construction forces and effects

AS 5100.2 section 21 requirements are suitable for adoption without modification.

Section 22: Load combinations

AS 5100.2 section 22 load combinations are presented by simple expressions that appear to neglect detailed consideration of the loads that are likely to coexist. For the SLS the number of load combinations to be considered precludes the use of manual methods and would require the use of a computerised process.

For the ULS, the *Bridge manual* considers a wider range of loads acting concurrently on the structure than do the AS 5100.2 provisions.

Adoption of the AS 5100 load combinations is not recommended. If AS 5100.2 were adopted, supplementary documentation would be required to incorporate the *Bridge manual* load combinations.

Section 23: Road signs and lighting structures

AS 5100.2 section 13 requirements are generally suitable for adoption but the design wind speeds should be reviewed and made consistent with the principles presented in AS/NZS 1170. Alignment with this code is important for building consent purposes.

Section 24: Noise barriers

As for road signs and lighting structures, the design requirements set out in AS 5100.2 for noise barriers are generally suitable for adoption but the design wind speeds should be reviewed and made consistent with the principles presented in AS/NZS 1170.

Appendix A: Design loads for medium and special performance level barriers

The differences between the requirements given in appendix A of AS 5100.2 and the corresponding *Bridge manual* provisions are relatively minor. Appendix A is generally suitable for adoption.

AS 5100.3: Foundations and soil supporting structures

Section 1: Scope

Section 1 is suitable for adoption should AS 5100.3 as a whole be adopted. It should be extended with supplementary documentation to incorporate requirements for the design of earthworks.

Section 2: Application

Section 2 is suitable for adoption should AS 5100.3 as a whole be accepted.

Section 3: Referenced documents

If AS 5100.3 were adopted additions, and possibly some exclusions, would need to be made to the referenced documents to incorporate documents required by the supplementary material.

Section 4: Definitions

Section 4 of AS 5100.3 is suitable for adoption as is.

Section 5: Notation

Section 5 of AS 5100.3 is suitable for adoption. Extension of the list of notations may be required to incorporate notation from any supplementary documentation used to support other adopted sections of AS 5100.3.

Section 6: Site investigation

AS 5100.3 section 6 requirements are generally suitable for adoption but if adopted supplementary documentation would be needed to cover additional requirements specified by the *Bridge manual*, including the confirmation of site conditions during construction.

Section 7: Design requirements

Section 7 of AS 5100.3 is generally suitable for adoption provided the other sections which it refers to are also adopted. If AS 5100.3 were adopted, supplementary documentation would be required to incorporate requirements for the capacity design of foundations and for the design of earthworks.

Section 8: Loads and load combinations

If AS 5100.3 section 8 were adopted, review and amendment of the following areas with supplementary documentation would be required:

- the design of spill-through abutments columns
- load factors for soil supporting structures where the loads are imposed predominantly from the soil
- the *Bridge manual* consideration of settlement and the requirement to consider dynamic and earthquake actions on earth retaining structures.

Section 9: Durability

Section 9 of AS 5100.3 is generally suitable for adoption. If AS 5100.5 were not adopted for concrete design, supplementary documentation would be required to state the durability requirements for concrete structures.

Section 10: Shallow footings

AS 5100.3 section 10 requirements are generally suitable for adoption. If AS 5100.3 were adopted, supplementary documentation would need to be included to retain the referenced design guidelines given in the *Bridge manual*.

Section 11: Piled foundation

Section 11 of AS 5100 is generally suitable for adoption, but would require supplementing with additional documentation to include the *Bridge manual* requirements for seismic resistance. In addition the following areas would require review:

- the location of the maximum design moments in laterally loaded piles
- the strength reduction factors at the top end of the range adopted by AS 2159 (AS 5100.3 requires strength reduction factors to be in accordance with this standard).

Section 12: Anchorages

AS 5100.3 section 12 requirements are generally suitable for adoption, but clarification on capacity reduction factors would be required. Reference is made to AS 5100.5 and AS 5100.6 for structural strength reduction factors, but these do not appear to be clearly defined in the sections on anchorages.

If AS 5100 were adopted, supplementary documentation would be required to incorporate the *Bridge manual* requirements for the corrosion protection of anchors and other *Bridge manual* requirements for anchored and soil nailed walls not included in AS 5100.3.

Section 13: Retaining walls and abutments

Section 13 of AS 5100.3 lacks adequate criteria for the performance of abutments and retaining walls under earthquake loads. Otherwise it is generally suitable for adoption subject to other parts of AS 5100 referred to also being adopted.

If AS 5100.3 were adopted, supplementary documentation would be required to incorporate the categorisation of walls and seismic performance criteria presented in the *Bridge manual*.

Section 14: Buried structures

Section 14 of AS 5100.3 is generally suitable for adoption; however, if adopted, supplementary documentation would be required to incorporate the *Bridge manual* provisions for earthquake resistant design of buried structures.

AS 5100.3 does not specifically cover corrugated metal structures, and so the standards cited by the *Bridge manual* should be reviewed and considered for inclusion.

Appendix A: Assessment of geotechnical strength reduction factors for piles

As indicated above for section 11, a review would be required of the strength reduction factors at the top end of the specified ranges given in this appendix.

Appendix B: On site tests of anchorages

Appendix B is suitable for adoption.

Other considerations – strength reduction factors

Throughout AS 5100.3, geotechnical strength reduction factors differ from one structural element type to another for the same method of assessment of geotechnical strength. In some cases these factors include allowance for the design life of the structure (ie whether permanent or temporary) which is usually taken into account in the load factors assigned to the design loading.

If AS 5100.3 were adopted, a review of the strength reduction factors and load factors would be required to ensure that they satisfy the required safety index.

AS 5100.4: Bearings and deck joints

AS 5100.4 has previously been reviewed and adopted by the *Bridge manual* as the standard for the design and performance of bearings and deck joints, supplemented by additional requirements set out in the *Bridge manual*, section 4.7. The AS 5100.4 provisions for the design of elastomeric bearings were not adopted. There is significant variation in the approach adopted by existing standards (AS 5100, BS 5400, AASHTO and Eurocodes) and uncertainty about which standards predict the characteristics of bearings most accurately. A review of the various specifications would be required to determine the most suitable approach for New Zealand conditions.

AS 5100.5: Concrete

The *Bridge manual* adopts NZS 3101 'Concrete structures'. However, NZS 3101:2006 is the latest edition and was adopted for the purpose of this project.

Section 1: Scope and general

Section 1 of AS 5100.5 would require significant amendment to be suitable for adoption. The required amendments include:

- alignment of the reinforcing steels acceptable for use with those specified in NZS 3101
- extension of the list of references to include New Zealand and international documents relevant to New Zealand practice
- an amalgamation of the AS 5100 and NZS 3101 list of information to be included on the drawings or in the specification
- a statement on the relationship of the standard to the NZBC
- requirements relating to construction review.

Section 2: Design requirements and procedures

With the exception of the sub-section on 'Other design requirements' most of section 2 of AS 5100.5 could be adopted without major modifications. Review of the strength reduction factors would be required and it would be necessary to include a strength reduction factor for when actions are derived from overstrengths of elements. A significant addition would need to be made under 'Other design requirements' to include clause 2.6 of NZS 3101, which stipulates additional design requirements related to earthquake effects. This would not be straightforward as the terminology relating to classification of structures, inelastic behaviour and capacity design are very different in the two standards.

Section 3: Loads and load combinations for stability, strength and serviceability

Section 3 of AS 5100.5 is generally suitable for adoption but modification would be required in line with the actions, outlined in section 2 of this report (below), considered necessary to adopt AS 5100.2.

Section 4: Design for durability

Section 4 of AS 5100.5 is generally suitable for adoption but significant changes would need to be made. In particular, the Australian exposure classifications would need to be replaced by the New Zealand ones and the tabulated covers for corrosion protection revised to be more in line with NZS 3101. Supplementary provisions giving requirements for corrosion protection of cast-in fixings and fastenings, and stating the need to take precautions against alkali silica reaction would need to be incorporated.

Section 5: Design for fire resistance

Section 5 of AS 5100.5 could be adopted without modification; however, it would be desirable to reference section 4 of NZS 3101 rather than AS 3600.

Section 6: Design properties of materials

With some minor modification section 6 of AS 5100.5 is suitable for adoption. The most significant difference between this section and NZS 3101 is the restriction on the use of the various ductility grades of reinforcement. This would need to be addressed. The more restrictive requirements of NZS 3101 in this area are based on earthquake loading considerations and would need to be adopted.

The shrinkage strain and creep factor coefficients given in AS 5100.5 are based on Australian climatic conditions and these would need to be modified for New Zealand conditions.

Section 7: Methods of structural analysis

With some minor modification section 7 of AS 5100.5 is suitable for adoption. The most significant difference between this section and NZS 3101 that would need to be addressed is the selection of the best location within the adopted standard for clauses on seismic analysis and deflection. Seismic design procedures are mainly covered in section 6 of AS 5100.5 and in section 2 of NZS 3101, and the clauses on calculation of deflections presented in section 6 of NZS 3101 are in sections 8 and 9 of AS 5100.5.

Clauses on the design for seismic loads using elastic analyses, which are presented in NZS 3101 and not included in AS 5100.5, would need to be added. Provisions for strut-and-tie analysis methods would also need to be added. The basis for the differences in the clauses on moment redistribution would need to be investigated and some modifications made to reflect the best practice in this area for both live load and seismic load cases.

Section 8: Design of beams for strength and serviceability

With some modification section 8 of AS 5100.5 could be adopted. Although the general approach used in both standards for the design of reinforced concrete and prestressed concrete beams is essentially the same, there is a large number of relatively minor differences that would need to be addressed by a careful review.

If AS 5100.5 were adopted, supplementary provisions would be needed to cover the NZS 3101 special provisions for ductility in earthquakes applying to reinforced concrete beam and slab members, and prestressed concrete beam members.

Section 9: Design of slabs for strength and serviceability

Significant modifications would need to be made to section 9 of AS 5100.5 before it could be adopted. Supplementary material would need to be incorporated to provide for two-way slab action, elastic plate analysis and the empirical membrane design method given in NZS 3101.

Section 10: Design of columns and tension members for strength and serviceability

With some modification section 10 of AS 5100.5 could be adopted. Although the general approach used in both standards for the design of reinforced concrete columns is essentially the same there is a large number of relatively minor differences that would need to be addressed by a careful review.

If AS 5100.5 were adopted, supplementary provisions would need to be incorporated to cover the NZS 3101 special provisions applying to reinforced concrete columns designed for ductility in earthquakes.

Section 11: Design of walls

Section 10 of AS 5100.5 could not be adopted without the addition of significant supplementary material, including special provisions applying to walls designed for ductility in earthquakes, to bring the provisions more in line with those of NZS 3101. A significant limitation of the provisions in AS 5100.5 for walls is that they do not cover members subjected to in-plane horizontal forces (reference is made to AS 3600 for this type of loading). The AS 5100.5 wall provisions are only applicable to the design for gravity loads on retaining walls and abutments and are not suitable for the design of laterally loaded pier walls.

Section 12: Design of non-flexural members, end zones and bearing surfaces

With a number of modifications section 12 of AS 5100.5 could be adopted. A significant amount of supplementary material on areas covered in NZS 3101 and not in AS 5100.5, including provisions for piles and pile caps and the application of strut-and–tie and elastic analysis methods for the design of anchor zones, would need to be incorporated.

Section 13: Stress development and splicing of reinforcement and tendons

With a number of modifications section 13 of AS 5100.5 could be adopted. Supplementary material on provisions presented in NZS 3101 and not covered in AS 5100.5, would need to be incorporated. In particular, additional material would be needed to cover the development of flexural reinforcement at critical sections and the special requirements for members designed for earthquake effects.

Section 14: Joints, embedded items, fixing and connections

Section 14 of AS 5100.5 could be adopted. Supplementary material, to incorporate provisions presented in NZS 3101 and not covered in AS 5100.5, would need to be incorporated. In particular, additional material would be needed to cover the design of cast-in anchors and the design of fixings for earthquake effects.

Section 15: Plain concrete members

The provisions in section 15 of AS 5100.5 could be adopted for use in New Zealand without significant modification.

Section 16: Material and construction requirements

If AS 5100.5 were adopted, section 16 would need to be replaced by the provisions of NZS 3109 'Specification for concrete construction', which is more appropriate for New Zealand conditions.

Section 17: Testing of members and structures

Section 17 of AS 5100.5 could be adopted without significant modification. It would be necessary to integrate these provisions with the *Bridge manual* procedures for assessing the strength of existing bridges by proof loading. There is some overlap and inconsistency between the AS 5100.5 and *Bridge manual* provisions but it would not be a major task to revise both sets of provisions to make them compatible.

Appendix A: Referenced documents

If AS 5100.5 were adopted, supplementary documentation would be required to incorporate reference to the standards listed in NZS 3101 that are relevant to concrete bridge design. Most of the documents listed in NZS 3101 that are not already in appendix A of AS 5100.5 would need to be included. Some of the Australian standards would need to be replaced by the equivalent New Zealand ones.

Appendix B: Design of segmental concrete bridges

Appendix B of AS 5100.5 could be adopted without modification. It provides useful background information applicable to the design of segmental concrete bridges.

Appendix C: Beam stability during erection

Appendix C of AS 5100.5 could be adopted without modification. It provides useful information relevant to the design and construction of bridges constructed with precast prestressed concrete beams.

Appendix D: Suspension reinforcement design procedures

Appendix D of AS 5100.5 could be adopted without modification. It provides useful information relevant to the design and construction of frequently used details in bridge superstructures.

Appendix E: Composite concrete member design procedures

Appendix E of AS 5100.5 could be adopted with minor modifications to make it consistent with the provisions of section 18 of NZS 3101. It includes detailed design procedures, additional to those given in NZS 3101, which are relevant to the design of commonly used types of bridge superstructures such as I beams with cast *in situ* slabs.

Appendix F: Box girders

Appendix F of AS 5100.5 could be adopted without modification. It provides useful design information for box girder superstructures that is not presented elsewhere in New Zealand design standards.

Appendix G: End zones for prestressing anchors

Parts of appendix G of AS 5100.5 could be adopted but it would need to be revised to include the more modern analysis procedures described in NZS 3101.

Appendix H: Standard precast prestressed concrete girder

A revised version of appendix H of AS 5100.5, presenting dimensions and section properties of standard bridge beam sections used in New Zealand, could be adopted.

Appendix I: References

If AS 5100.5 were adopted, a much more comprehensive list of references would need to be incorporated, based on those in the commentary to NZS 3101 that are relevant to concrete bridge design.

NZS 3101 Material not included in AS 5100.5

The following sections of NZS 3101, containing parts relevant to bridge design, do not receive significant coverage in AS 5100.5 and would need to be considered in supplementary documentation if AS 5100.5 were adopted.

Section 13 Design of diaphragms

Although the provisions of section 13 of NZS 3101 apply to diaphragms in buildings some of them are relevant to bridge design.

Section 14 Design of footings, piles and pile caps

The provisions of section 14 of NZS 3101 apply to the structural design of isolated and combined footings. Basic principles for the structural design of piles are included. The provisions of section 14 are applicable to both buildings and bridges.

AS 5100.5 contains very few provisions specifically related to the design of footings and pile caps and no provisions for the structural design of piles.

Section 15 Design of beam column joints

The provisions of section 15 of NZS 3101 apply to the design of beam column joints subjected to shear induced by gravity and earthquake loads. Although the provisions are directed mainly towards building frames, they are also relevant to bridge pier frames and joints at the intersections of bridge pier columns with footings. If AS 5100 were adopted, supplementary information on the design of beam column joints would need to be incorporated.

Bridge manual provisions for concrete bridge design

The *Bridge manual* requires the design of concrete bridges to be in accordance with NZS 3101, with modifications and additional provisions in the following areas:

- crack widths
- design for durability
- prestressing tendon losses
- minimum thickness of prismatic flexural members
- reinforced concrete deck slab design.

The *Bridge manual* supplementary material for prestressing tendon losses and reinforced concrete deck slab design is not covered by the AS 5100.5 provisions and if AS 5100.5 were adopted supplementary material would still be required to cover these areas. A detailed review of the crack width and durability design provisions of AS 5100.5 and NZS 3101 would also be required.

Limitation of NZS 3101 for bridge design

NZS 3101 states that although it has been developed to be generally applicable to the design of bridges, and is adopted by the *Bridge manual*, some aspects are recognised as not being adequately covered. It further states that aspects of bridge design for which reference to technical literature should be made include design for the following:

a) the combination of shear, torsion and warping in box girders

b) deflection control taking into account the effects of creep, shrinkage and differential shrinkage and differential creep

c) stress redistribution due to creep and shrinkage

d) the effects of temperature change and differential temperature (refer to the *Bridge manual* for these design actions)

e) the effects of heat of hydration. This is particularly an issue where thick concrete elements are cast as second stage construction and their thermal movements are restrained by previous construction

f) shear and local flexural effects, which may arise where out-of-plane moments are transmitted to web or slab members, or where the horizontal curvature of post-tensioned cables induces such actions

g) seismic design of piers, where the curvature ductility demand is greater than given in table 2.4 (NZS 3101).

Although omissions of the above items are a limitation of NZS 3101, with the exception of items (d) and (f), these areas are not adequately addressed by the provisions of AS 5100.5. If AS 5100.5 were adopted, supplementary information on the other bridge design aspects listed above would be desirable.

AS 5100.6: Steel and composite construction

The *Bridge manual* adopts NZS 3404 for design in steel, except for steel box girders. For steel box girders with composite concrete decks AS 5100.6 is adopted. For other box girders BS 5400 parts 3, 5 and 10 are adopted.

Section 1: Scope and general

Section 1 of AS 5100.6 is generally suitable for application in New Zealand. If AS 5100 were adopted, the referenced standards, both within this section and throughout AS 5100.6, would need to be reviewed and expanded to include New Zealand and international standards that are relevant to design and construction in New Zealand. Consideration should be given to incorporating a clause presenting definitions, as has been provided in other parts of AS 5100 and in NZS 3404. Differences in notation would need to be resolved if parts of NZS 3404 were retained. The contents of NZS 3404 sections 1.5 'Use of alternative materials and methods' and 1.6 'Design and construction review' should also be incorporated for New Zealand practice.

Section 2: Materials

Section 2 of AS 5100.6 is generally suitable for adoption subject to amendment to incorporate standards for the wide range of materials supplied in the New Zealand market and standards appropriate to concrete construction in New Zealand.

Section 3: General design requirements

Section 3 of AS 5100.6 is generally suitable for adoption. If AS 5100 were adopted supplementary documentation would be needed to explicitly incorporate a requirement to design for earthquakes, and if necessary, to incorporate limitations on deflection and vibration consistent with those associated with AS 5100.2. Definitions for the use of general and structural purpose (GP and SP) welds should also be provided.

The AS 5100.6 provisions for corrosion resistance should be extended to include the corrosion protection specified in NZS 3404 appendix C and to include requirements for weathering steels, not currently covered by either standard.

Section 4: Methods of structural analysis

Section 4 of AS 5100.6 is generally suitable for adoption subject to it being supplemented with additional documentation to incorporate the requirements related to seismic resistance contained within NZS 3404. Supplementary documentation would also be required to incorporate the additional analysis approaches (elastic analysis with moment and shear redistribution, and plastic analysis) included in NZS 3404 with the limitations and exclusions which are appropriate for gravity load design of bridges.

A review of the analysis procedure given in section 4 of AS 5100.6 for longitudinal shear would be required to ensure that at the ULS adequate shear capacity was provided between the points of zero and maximum moment to transfer the capacity of the deck slab across the interface with the steel beam, particularly in continuous beams.

Section 5: Steel beams

Section 5 of AS 5100.6 is generally suitable for adoption subject to supplementary documentation being prepared to incorporate the requirements contained in NZS 3404 related to seismic resistant design.

Where NZS 3404 presents requirements omitted from section 5 of AS 5100.6, these should be incorporated through supplementary documentation.

Section 6: Composite beams

Providing the ratio of the ULS loading to the SLS loading acting on a composite section does not exceed 1.8, section 6 of AS 5100.6 is generally suitable for adoption for the design of composite beams. If AS 5100.6 were adopted supplementary documentation would be required to incorporate the seismic design requirements contained within the corresponding section of NZS 3404.

There is a significant difference between AS 5100.6 and NZS 3404 in the calculation of strength associated with the design of transverse reinforcement. A review of these provisions would be required.

Section 7: Composite box girders

Section 7 of AS 5100.6 has already been adopted by the *Bridge manual*.

Section 8: Transverse members and restraints

Section 8 of AS 5100.6 is suitable for adoption as is. It extends the requirements of NZS 3404 that are particularly applicable to bridges.

Section 9: Members subjected to axial tension

Section 9 of AS 5100.6 is suitable for adoption subject to the inclusion of supplementary documentation to incorporate the seismic design requirements presented in NZS 3404.

Section 10: Members subjected to axial compression

Section 10 of AS 5100.6 is generally suitable for adoption subject to supplementary documentation being prepared to incorporate the seismic design requirements of NZS 3404.

Section 11: Members subjected to combined actions

Section 11 of AS 5100.6 is generally suitable for adoption subject to supplementary documentation being prepared to incorporate the NZS 3404 provision for plastically yielding elements to have full lateral restraint.

Section 12: Connections

Section 12 of AS 5100.6 is generally suitable for adoption subject to supplementary document being prepared to incorporate the following areas:

- the seismic design requirements contained within the corresponding section of NZS 3404
- pin design rules in NZS 3404 based on tests by the Heavy Engineering Research Association (HERA) and incorporated in a 2001 amendment. They should, therefore, be preferred to the rules given in AS 5100.6
- a requirement for splices in compression members between points of lateral support to be designed for a minimum moment as well as a minimum axial load
- a requirement for the local effect of member connections on hollow sections to be considered
- a requirement for the need for higher weld quality in some situations (eg to provide for fatigue) to be considered. The guidance provided by NZS 3404 on weld category selection should also be retained

- an increase in the range of applications for plug welds, as allowed by NZS 3404
- a correction to amend the size of plug and slot welds for plates less than 12 mm thick
- a requirement for welding consumables for butt welds to produce a minimum strength not less than the parent metal.

Section 13: Fatigue

Section 13 of AS 5100.6 is generally suitable for adoption subject to the supplementary documentation addressing the following:

- an amalgamation of the capacity factor requirements of AS 5100 and NZS 3404
- a review of the fatigue loading to achieve consistency with the design traffic loadings adopted for use in New Zealand
- clarification and correction of the detail categories
- clarification of the definitions for f_{rnc} and f_{rsc}.

Section 14: Brittle fracture

Section 14 of AS 5100 is generally suitable for adoption, subject to incorporation of the following NZS 3404 provisions through supplementary documentation:

- requirements for welding consumables and bolts
- the map of isotherms for New Zealand and reference to the National Institute of Water and Atmospheric Research as the source for information on abnormally low local ambient temperatures
- inclusion of AS 1554.5 as a standard to be complied with where appropriate
- requirements for the permissible temperature to be raised for category 1 and 2 members of seismic resisting systems
- inclusion of the BS EN 10025 and JIS G 3106 steel grades, as these may also be encountered in New Zealand.

Section 15: Testing of structures or elements

Section 15 of AS 5100.5 is generally suitable for adoption subject to supplementary documentation being prepared to incorporate:

- the requirement for the test load to be applied for at least five minutes
- references to the *Bridge manual* as the source for the design loading to be used as the test load
- reference to the *Bridge manual* for load application, instrumentation and procedure
- acceptance criteria for strength and ductility testing for seismic applications.

Appendix A: Elastic resistance to lateral buckling

Appendix A of AS 5100.6 is generally suitable for adoption.

Appendix B: Strength of stiffened web panels under combined actions

Appendix B of AS 5100.6 is generally suitable for adoption.

Appendix C: Second order elastic analysis

The wording of appendix C of AS 5100.6 has been amended over time, via AS 4100, from the original wording presented in NZS 3404, with some changes in meaning that may not have been intended. If adopted, appendix C should be subjected to a detailed review.

Appendix D: Eccentrically loaded double-bolted or welded single angles in trusses

Appendix D of AS 5100.6 is suitable for adoption subject to:

- a review of the need to limit applicability to compression members with slenderness ratios of $L/r_y < 150$
- confirmation or correction of the expression for 'e' for the case of angles on opposite sides of the truss chord.

Appendix E: Nominal section moment capacity for composite sections under sagging moments

Although the simplified method of calculation in appendix E of AS 5100.6 is not consistent with NZS 3101 it is considered suitable for adoption. In view of the level of accuracy in the effective slab rules the approximate concrete stress block appears satisfactory and the calculation method is well established.

Appendix F: Interaction curves for composite columns

Appendix F of AS 5100.6 is suitable for adoption for the design of segments of concrete infilled steel tube columns where full composite action can be assumed.

Appendix G: Fabrication

Appendix G of AS 5100.6 is suitable for adoption subject to the addition of the NZS 3404 requirement limiting the yield stress of steel where required to satisfy seismic design requirements.

Appendix H: Erection

Appendix H of AS 5100.6 is generally suitable for adoption; however, the material contained in NZS 3404 and omitted from AS 5100.6 should be incorporated in supplementary documentation.

Appendix I: Modification of existing structures

Appendix I of AS 5100.6 is suitable for adoption.

NZS 3404 Material not included within AS 5100.6

The following sections of NZS 3404, potentially relevant to bridge design, do not receive significant coverage in AS 5100.6. If AS 5100.6 were adopted, supplementary documentation based on the NZS 3404 provisions, would need to be prepared to include these areas.

Section 12: Seismic design

As earthquake loads are usually a significant consideration in the design of bridges in New Zealand, except perhaps in the zones of lowest seismicity, it is essential that the design standard for bridges in New Zealand include requirements for seismic design.

Appendix A: Referenced documents

A much more limited listing appears in AS 5100.6.

Appendix B: Maximum levels of ductility demand on structural steel seismic-resisting systems

This area is important for seismic design and is related to section 12 of NZS 3404.

Appendix C: Corrosion protection (brief coverage only in AS 5100.6 clause 3.7)

AS 5100.6 is deficient in its treatment of corrosion protection.

Appendix L: Inspection of bolt tension using a torque wrench

If AS 5100.6 were adopted, the requirements of appendix L of NZS 3404 for the inspection of bolted connections would need to be incorporated into the AS 5100 appendix for erection.

Appendix M: Design procedure for bolted moment-resisting endplate connections

The requirements of appendix M of NZS 3404 are relevant to the seismic design of frames.

AS 5100.7: Rating of existing bridges

Section 1: Scope and general

Section 1 of AS 5100.7 sets out appropriate requirements and principles for the evaluation of bridge structures and is suitable for adoption. However, it does not cater adequately for the needs of the Transit NZ Highway Permit System and if adopted supplementary documentation would be required to incorporate provisions that address the information needs of the Highway Permit System and administration of bridge posting under the Heavy Motor Vehicle Regulations.

Section 2: Referenced documents

The referenced documents in section 2 of AS 5100.7 are appropriate for bridges built in the past and future to AS 5100 requirements. If AS 5100.7 were adopted, supplementary documentation would be required to incorporate the design standards that applied to New Zealand bridges in the past.

Section 3: Notation

Section 3 of AS 5100.7 is suitable for adoption subject to the sections that contain the notation also being adopted. If AS 5100.7 were adopted, notation in any supplementary documentation would need to be harmonised with this notation.

Section 4: Rating philosophy

The AS 5100.7 section 4 outlines of the rating philosophy, principles and methodology are suitable for adoption. However, if section 4 were adopted it would need to be supplemented by the *Bridge manual* requirements which set out specifically the relevant reference rating loads appropriate to New Zealand; set modelling assumptions to be adopted for a variety of conditions; and provide methods for the evaluation of concrete and timber decks.

Section 5: Assessment of load capacity

Section 5 of AS 5100.7 is suitable for adoption but would need to be supplemented by the *Bridge manual* requirements for the determination of material characteristic strengths, including information on historical characteristic strengths of materials, and criteria for the strength testing of materials and analysis of the test results.

Section 6: Load testing

Section 6 of AS 5100.7, as a general specification of load testing requirements, is suitable for adoption; however, supplementary documentation would be needed to incorporate the *Bridge manual* requirements for proof loading.

Section 7: Assessment of the actual loads

Section 7 of AS 5100.7, setting out the general principles and methods for assessing the loads to be applied in the rating analysis is generally suitable for adoption, subject to AS 5100.2 also being adopted. If AS 5100.7 were adopted, the *Bridge manual*'s prescriptive requirements, geared to providing specific data in a consistent form for defined rating live loads for use in Transit's Overweight Permit System (TOPS) would need to be retained and incorporated through the preparation of supplementary documentation.

Section 8: Fatigue

Section 8 of AS 5100.7 is generally suitable for adoption.

Topics not included in AS 5100, requiring coverage

The *Bridge manual* and the supporting materials design standards referenced by it include a number of topics not included at all or to any significant extent in AS 5100. Topics essentially not covered by AS 5100 are:

- bridge design statement
- influence of approaches
- aesthetics
- special studies
- design of earthworks
- seismic design of steel structures
- seismic design of concrete structures
- empirical design of reinforced concrete deck slabs based on assumed membrane action
- earthquake resistant design – encompassing:
    - design philosophy
    - ductility demand
    - analysis methods
    - member design criteria, foundation design and liquefaction
    - structural integrity and provision for relative displacements
    - earth retaining walls
- structural strengthening
- bridge side protection – Transit's specific requirements in respect to:
    - barrier acceptance criteria
    - standard solutions
    - design of deck slabs to resist barrier forces
    - pedestrian and cyclist barriers, and combined pedestrian/traffic barriers
    - geometric layout, end treatment and transitions

  - barrier performance level 3 standard design
- toroidal rubber buffers
- lightly trafficked rural bridges
- bridge site information summary.

Conclusions

Conclusions on Part 1: Scope and general principles

Six of the AS 5100.1 sections could be adopted without significant change, seven would require minor supplementary documentation and three: section 6 'Design philosophy, section 7 'Waterways and flood design', and section 10 'Road traffic barriers' would require major supplementary documentation.

Conclusions on AS 5100.2: Design loads

Seven of the 24 AS 5100.2 sections could be adopted without significant change, 14 would require minor supplementary documentation, four would require major supplementary documentation and three: section 6 'Road traffic', section 14 'Earthquake forces', and section 22 'Load combinations' would probably need replacement.

The three sections of AS 5100.2 requiring replacement would essentially be replaced by the present or enhanced *Bridge manual* provisions so adopting AS 5100.2 would not involve major review and development work.

Conclusions on AS 5100.3: Foundations and soil supporting structures

Five of the 14 AS 5100.3 sections could be adopted without significant change, nine would require minor supplementary documentation, and three: section 8 'Loads and load combinations', section 12 'Anchorages', and section 13 'Retaining walls and abutments' would require major supplementary documentation.

Conclusions on AS 5100.4: Bearings and deck joints

AS 5100.4 has already been adopted by the *Bridge manual* subject to a number of additional requirements set out in the manual. Adoption of a part of AS 5100.4 with supplementary requirements covered by the *Bridge manual* has proved to be an acceptable approach for the design of bridge components.

Conclusions on AS 5100.5: Concrete

Only one of the 17 AS 5100.5 sections could be adopted without significant change, five would require minor supplementary documentation, nine would require major supplementary documentation and one: section 16 'Materials and construction requirements', would need replacement.

AS 5100.5 is one of the most important parts of the whole document for New Zealand in that most bridges in New Zealand are constructed of concrete or have major concrete components, and this part should also include detailed earthquake design provisions. The overall conclusion from this review is that there would be no advantage in adopting AS 5100.5 for concrete bridge design in New Zealand. A better approach would to be to continue using NZS 3101 and add supplementary material to cover aspects of bridge design not adequately addressed in NZS 3101. This supplementary material should incorporate or include reference to some of the material in AS 5100.5, particularly the design information in the appendices.

The main reasons for preferring NZS 3101 to AS 5100.5 for concrete bridge design in New Zealand are as follows:

- The non-seismic sections of NZS 3101 are largely based upon the American Concrete Institute (ACI) standard ACI 318-02. Because of the considerable resources of ACI this standard is frequently updated to incorporate the latest developments in design practice, structural analysis and concrete research. The ACI standard has world-wide acceptance and has been adopted as the basis of concrete design standards in many non-European countries.
- Some of the provisions of AS 5100.5 appear rather dated and may have been based on earlier versions of the ACI standard.
- NZS 3101 was first published in 1982. (It replaced a provisional standard 3101P containing similar provisions. The 1978 edition of the MWD *Highway bridge design brief* required concrete bridges to be designed in accordance with DZ 3101 – a draft forerunner to NZ 3101P). Prior to the adoption of NZS 3101, ACI-77 and earlier versions of this standard were frequently used or referenced for the design of bridge and other concrete structures in New Zealand. (For example ACI-63 was used in New Zealand in the late 1960s.) Because of the close relationship of NZS 3101 to the ACI concrete design standard and the application of NZS 3101 for the design of most concrete structures in New Zealand since it was first introduced in the 1970s, New Zealand engineers have become very familiar with the basis of the provisions, their application in design and the notation and nomenclature. Changing to a different concrete design standard would be disruptive and have economic disadvantages for many design offices.
- Adoption of AS 5100.5 for bridge design would result in a loss of consistency between bridge design and the design of other concrete structures in New Zealand. This would be a particular disadvantage for smaller design agencies where the same personnel frequently design a wide range of concrete structures. Whether there are advantages in having separate materials design standards for different types of structures (eg buildings and bridges) is a debatable point. Although separate standards for buildings and bridges are used in Australia and the United States, this is not the case in Europe where the materials codes (Eurocodes) have generally been developed to cover the range of commonly designed structures. In New Zealand, where specialist resources are limited, it seems best that materials design codes should cover the widest possible range of structures.
- NZS 3101 is more comprehensive than AS 5100.5, covering a wider range of topics relevant to bridge design in New Zealand and providing more prescriptive detail. The basis of the design provisions and background testing and research is referenced in a comprehensive commentary to NZS 3101. A commentary to AS 5100.5 (AS 5100.5 supp 1 2008) has recently been published but was not available when the research for this project was completed
- If AS 5100.5 were adopted a major supplement would be required to incorporate seismic design requirements. This would be difficult and time consuming to prepare, and would involve more than merely abstracting the seismic design provisions given in NZS 3101 as these are interrelated to the provisions and nomenclature used for non-seismic aspects of the design of many of the structural member types covered in the standard.

The main disadvantage of adopting NZS 3101, rather than AS 5100.5, is that there are a number of relevant provisions in AS 5100.5 that are not adequately covered in NZS 3101. These include:

- crack width limitations for bridges
- cover to tendons and ducts
- shrinkage and creep effects
- unbonded tendons
- curved prestressing ducts
- requirements for halved joints and hanger steel
- design of movement joints
- prototype testing and testing of hardened concrete
- guidelines for segmental, composite concrete and box girder bridges.

Many of the above provisions that not adequately covered in NZS 3101 are important for bridge design but they tend to be 'stand-alone' items that do not impinge on other provisions in the standards. For this reason, they would be relatively easy to incorporate by supplementary documentation or by direct reference to the AS 5100 provisions.

The main advantage of adopting AS 5100.5 would be the development of consistency between the concrete bridge design requirements of New Zealand and Australia. In particular, the larger New Zealand consultancies, who undertake international work, would benefit most from uniformity of design standards. Being able to draw on the specialist resources of both countries for development and revision of the standards would also be an obvious advantage.

Overall, the disadvantages of adopting AS 5100.5 for New Zealand would outweigh the advantages.

Conclusions on AS 5100.6: Steel and composite construction

Only one of the eight AS 5100.6 sections could be adopted without significant change, three would require minor supplementary documentation, and four: section 1 'Scope and general', section 4 'Rating philosophy, section 5 'Assessment of load capacity', and section 6 'Composite beams', would require major supplementary documentation. This major documentation would be mainly required to incorporate seismic design requirements and would probably take the form of a separate section with cross-referencing from the other sections.

Rather than the adoption of AS 5100.6 with supplementary material it would be desirable to have a joint AS/NZS standard for steel structures to cover the contents of AS 4100, AS 5100.6 and NZS 3404. The differences between these three codes are not major, and there would be significant advantages in New Zealand and Australia adopting a joint standard that covered both building and bridge steel structures. However, considering that the development of separate building and bridge concrete codes in Australia is a reasonably recent development it seems unlikely that reverting back to a unified standard would gain acceptance with all of the various controlling agencies. An alternative approach that would be acceptable within New Zealand would be to amend NZS 3404 to provide a more comprehensive cover of bridge design requirements. An interim approach would be to maintain the status quo with the *Bridge manual* adopting NZS 3404 but with additional supplementary material to incorporate relevant AS 5100.6 provisions not included in NZ 3404.

One shortcoming of AS 5100.6 identified in this review is that there are many errors in the design empirical equations. Corrections to many of these have been published in a document issued by the Brisbane City Council. Formal correction of the code by issue of amendments by the controlling authority, Standards Australia, appears to be a slow process.

Some of the advantages and disadvantages outlined above of adopting AS 5100.5 for New Zealand also apply to AS 5100.6. Again the overriding considerations, which sway the choice in favour of retaining NZS 3404, are the difficulty of preparing supplementary material for AS 5100.6 to incorporate seismic design requirements, and the advantage in New Zealand of maintaining consistency between building and bridge material design standards.

Conclusions on AS 5100.7: Rating of existing bridges

Four of the 15 AS 5100.7 sections could be adopted without significant change, nine would require minor supplementary documentation, and four: section 3 'General design requirements', section 4 'Methods of structural analysis', section 5 'Assessment of load capacity', and section 7 'Assessment of the actual loads', would require major supplementary documentation.

AS 5100.7 provides requirements and guidance of a general nature applicable to the rating of bridges for live load capacity and is generally suitable for adoption. The *Bridge manual's* section 6: 'Evaluation of bridges and culverts', is specifically focused on providing the information needed for posting bridges in accordance with New Zealand's Heavy Motor Vehicle Regulations and for the operation of TOPS. It is essential to retain this section of the *Bridge manual* and AS 5100.7 should not be adopted in place of it. It would be appropriate to adopt AS 5100.7 as a guideline document in its present form with minor supplementary documentation, to stand alongside the *Bridge manual's* section 6.

Conclusions on topics not included in AS 5100 requiring coverage

Most of the material covered in the *Bridge manual* that is not included in AS 5100 is important for bridge design in New Zealand and is not adequately covered in other standards or design guidelines. If AS 5100 were to be adopted, this material should be incorporated by the preparation of a supplementary document and the earthquake resistant design provisions of the *Bridge manual* would need to replace the earthquake load provisions presented in AS 5100.2.

Overall conclusions on adopting AS 5100

Aligning the *Bridge manual* to AS 5100 by supplements is more complicated than may at first appear, as significant differences arise in many areas including seismic design, design live loading and slab design. As summarised above, without extensive supplements AS 5100 does not meet many of the New Zealand design requirements. It would be cumbersome and rather impractical to carry out design using an extensively supplemented document.

Conclusions on materials codes

Materials design standards should be comprehensive stand-alone documents (such as NZS 3101 and NZS 3404), and should be referred to by structure design standards, such as the *Bridge manual*. It would be a retrograde step if New Zealand were to convert to the current Australian practice of structure-specific materials design standards. The two Australian standards for the design of concrete structures – AS 3600 and AS 5100.5, and for the design of structural steel – AS 4100 and AS 5100.6, lead to the possibility of conflict and confusion between two sources of similar information. Producing, maintaining and synchronising them also requires far more scarce technical resources than would be needed if one materials design standard was produced to cover all common structural applications of the material – as is the aim with NZS 3101 and NZS 3404. A compromise approach seems to be that taken by the Eurocodes, where materials standards are presented with structure-specific sections, as appropriate, and 'national annexes' to cover local requirements.

Conclusions on harmonisation of codes

It would be very desirable to have bridge design standards common to New Zealand and Australia, as has been successfully achieved in areas such as the loading standard AS/NZS1170. Many current differences arise from traditional practice, rather than from necessary technical differences, and could be eliminated by adjustment of local practices. Basic differences of practice (eg live loading, seismic) could be covered by separate sub-sections, as has been done in AS/NZS 1170. Such a combined standard should be produced by a joint committee from the two countries. If harmonisation of bridge design standards is to be achieved, agreement on this approach is required before any other paths for harmonisation are followed.

A separate step in any harmonisation would be to produce joint AS/NZS concrete and steel materials design standards to apply to all common structural applications. Such a project would require considerable resources to complete, and would have a greater chance of success if the Australians could be convinced that structure specific materials design standards are not required.

Conclusions on administrative matters

The Austroads Bridge Design Code that preceded AS 5100 was administered by the Austroads roading authority. Now that AS 5100 is under the control of Standards Australia it is understood that making revisions or amendments is a more protracted process than was previously the case. An advantage of retaining the *Bridge manual* is that it would still be controlled by an agency with a vested interest in expediting revisions and improvements.

Table E1 Summary table for AS 5100.1.

Section	Major issues	Proposed action if AS 5100.1 were adopted				
		Adopt in present form	Minor supplement	Major supplement	Replace	N/A
1 Scope		✓				
2 Application		✓				
3 Referenced documents	Need to incorporate NZ standards and other documents as appropriate		✓			
4 Definitions			✓			
5 Notation			✓			
6 Design philosophy	Highly desirable to align with AS/NZS 1170			✓		
7 Waterways and flood design	*Bridge manual* much more specific			✓		
8 Environmental impact		✓	✓			
9 Geometric requirements	Detailed review of the implication of differences required.		✓			
10 Road traffic barriers	Detailed review of the implication of differences required. Retain Transit's current standard and preferred solutions.			✓		
11 Collision protection		✓				
12 Pedestrian and bicycle barriers			✓			
13 Noise barriers		✓				
14 Drainage			✓			
15 Access for inspection and maintenance		✓				
16 Utilities			✓			
17 Skew railway bridges						✓
18 Camber on railway bridges						✓
Appendix A: Matters for resolution before design commences	Need to reference relevant NZ and Transit documents.		✓			
Appendix B: Road barrier performance level selection method	Detailed review of the differences in road type and curvature factors required.		✓			

Table E2 Summary table for AS 5100.2.

Section	Major issues	Proposed action if AS 5100.2 were adopted				
		Adopt in present form	Minor supplement	Major supplement	Replace	N/A
1 Scope and general		✓	✓			
2 Referenced documents			✓			
3 Definitions		✓				
4 Notation		✓	✓			
5 Dead loads	Detailed review of the implications of differences required.		✓			
6 Road traffic	AS 5100 design traffic loading is very much heavier than *Bridge manual* design traffic loading				✓	
7 Pedestrian and bicycle-path load	Review of the differences required.		✓			
8 Railway traffic						✓
9 Minimum lateral restraint capacity			✓			
10 Collision loads	Detailed review of requirements related to train collision required.			✓		
11 Kerb and barrier design loads and other requirements for road traffic bridges	Detailed review of the differences is required			✓		
12 Dynamic behaviour	Load simulation and acceptance criteria are very different. A detailed review is required.			✓		
13 Earth pressure			✓			
14 Earthquake forces	AS 5100 provides insufficient coverage of this usually dominant aspect of structural design in NZ				✓	
15 Forces resulting from water flow			✓			
16 Wind loads				✓		
17 Thermal effects	Detailed review of differences required. Calibration required to NZ conditions.		✓			
18 Shrinkage, creep and prestress effects		✓	✓			
19 Differential movement of supports			✓			

Section	Major issues	Proposed action if AS 5100.2 were adopted				
		Adopt in present form	Minor supplement	Major supplement	Replace	N/A
20 Forces from bearings		✓	✓			
21 Construction forces and effects		✓				
22 Load combinations	The AS 5100 formulation of load combinations is significantly different to the *Bridge manual*. A detailed review is required.			✓?	✓?	
23 Road signs and lighting structures			✓			
24 Noise barriers			✓			
Appendix: Design loads for medium and special performance level barriers		✓				

Table E3 Summary table for AS 5100.3.

Section	Major issues	Proposed action if AS 5100.3 were adopted				
		Adopt in present form	Minor supplement	Major supplement	Replace	N/A
1 Scope		✓				
2 Application		✓				
3 Referenced documents			✓			
4 Definitions		✓				
5 Notation		✓	✓?			
6 Site investigations			✓			
7 Design requirements	Review required of strength reduction factors throughout this part.		✓			
8 Loads and load combinations				✓		
9 Durability			✓			
10 Shallow footings			✓			
11 Piled foundations	Review required of strength reduction factors. Earthquake resistant design requirements need incorporating.		✓			
12 Anchorages	Review and clarification required of strength reduction factors. Supplement specification for corrosion protection of anchors. Interrelated with retaining walls, earthquake resistant design requirements need incorporating			✓		
13 Retaining walls and abutments	Interrelated with anchorages, earthquake resistant design requirements need incorporating			✓		
14 Buried structures	Specific requirements for flexible metal plate culverts need incorporating.		✓			
Appendix: Assessment of geotechnical strength reduction factors for piles	Review required of strength reduction factors		✓			
Appendix: On-site assessment tests of anchorages		✓				

Table E4 Summary table for AS 5100.5.

Section	Major issues	Proposed action if AS 5100.5 were adopted				
		Adopt in present form	Minor supplement	Major supplement	Replace	N/A
1 Scope and general	Alignment of reinforcing steels acceptable for use in NZ. Relationship of AS 5100 to the NZ Building Code.			✓		
2 Design requirements and procedures	Need to incorporate NZS 3101 requirements for earthquake effects. Not straightforward because of different terminology related to classification of structures, inelastic behaviour and capacity design.			✓		
3 Loads and load combinations for stability, strength and serviceability	*Bridge manual* load combinations need to be retained.		✓			
4 Design for durability	AS 5100 exposure classifications need to be replaced and a number of corrosion protection issues addressed.			✓		
5 Design for fire resistance		✓				
6 Design properties of materials	Alignment of reinforcing steels acceptable for use in NZ. Creep and shrinkage coefficients need to be modified for NZ conditions.		✓			
7 Methods of structural analysis	Location within adopted standard for clauses on seismic analysis and deflection. Addition of clauses on seismic design using elastic analysis.		✓			
8. Design of beams for strength and serviceability	Special provisions for members and frames designed for ductility in earthquakes.			✓		
9 Design of slabs for strength and serviceability	Two-way slab action, elastic plate analysis and membrane design method are not covered.			✓		
10 Design of columns and tension members for strength and serviceability	Design of transverse reinforcement for shear, confinement and lateral restraint of longitudinal bars. Special provisions applying to columns designed for ductility in earthquakes.			✓		
11 Design of walls	AS 5100 does not contain provisions for walls subjected to horizontal in-plane forces. Special provisions applying to walls designed for ductility in earthquakes.			✓		
12 Design of non-flexural members, end	AS 5100 does not contain adequate provisions for piles			✓		

Section	Major issues	Proposed action if AS 5100.5 were adopted				
		Adopt in present form	Minor supplement	Major supplement	Replace	N/A
zones and bearing surfaces	and pile caps. AS 5100 does not cover the application of strut-and-tie and elastic analysis methods for anchor zone design.					
13 Stress development and splicing of reinforcement	Development of reinforcement at critical sections and special requirements for members designed for earthquake effects.			✓		
14 Joints, embedded items, fixings and connections	AS 5100 does not cover the design of cast-in anchors or the design of fixings for earthquake effects.		✓			
16 Materials and construction requirements	NZS 3109 is more appropriate for NZ conditions.				✓	
17 Testing of members and structures	Consistency with the *Bridge manual* provisions.		✓			
App. B Design of segmental girder bridges		✓				
App. C Beam stability during erection		✓				
App. D Suspension reinforcement design procedures		✓				
App. E Composite concrete design procedures	Needs revision to be consistent with provisions of section 18 of NZS 3101.		✓			
App. F Box girders		✓				
App. G End zones for prestressing anchors	Needs revision to incorporate modern methods of analysis.			✓		
App. H Standard precast prestressed concrete girder	Needs revision to only include standard beam sections used in NZ.		✓			
App. I References	A more comprehensive list of references is required.			✓		
NZS 3101 material not included within AS 5100	NZS 3101 section 13 – Design of diaphragms AS 5100.5 does not contain provisions related to the diaphragm action of decks under horizontal earthquake loads. NZS 3101 section 14 – Design of footings, piles and pile caps. AS 5110.5 does not contain adequate provisions for the design of footings and pile caps. Two-way shear design is a specific omission. No provisions are included for			✓		

Section	Major issues	Proposed action if AS 5100.5 were adopted				
		Adopt in present form	Minor supplement	Major supplement	Replace	N/A
	laterally loaded piles. NZS 3101 section 15 – Design of beam column joints AS 5100.5 does not contain any provisions specifically related to the design of beam column joints.					

Table E5 Summary table for AS 5100.6: Supplementary documentation required if AS 5100 adopted.

Section	Major issues	Proposed action if AS 5100.6 were adopted				
		Adopt in present form	Minor supplement	Major supplement	Replace	N/A
1 Scope and general	Notation differences need to covered in a usable way.		✓			
2 Materials			✓			
3 General design requirements	Incorporate a requirement to design for earthquake resistance, and limitations on deflection and vibration. Extend requirements for corrosion protection and include provisions for the use of weathering steels (refer table E6)			✓*		
4 Methods of structural analysis	Incorporate requirements related to analysis for seismic resistance. Permit additional forms of analysis where applicable to bridge design. Review and ensure consistency in approach for deriving effective flange width between concrete and steel design sections. Review adequacy of requirements for longitudinal shear design in continuous composite members at the ULS.			✓*		
5 Steel beams	Rectify what appear to be numerous errors in this section. Incorporate requirements for seismic resistant design. Incorporate relevant NZS 3404 material omitted.			✓*		
6 Composite beams	Rectify equation 6.6.4.4.(2) Incorporate requirements for seismic resistant design Reviews are required of: • the strength of channel shear connectors • the calculation of strength associated with the design of transverse reinforcement • the use of profiled sheeting as permanent formwork			✓*		
7 Composite box girders	Review recommended for errors	✓				
8 Transverse members and restraints		✓				
9 Members subject to axial tension	Incorporate requirements for seismic resistant design		✓			

Section	Major issues	Proposed action if AS 5100.6 were adopted				
		Adopt in present form	Minor supplement	Major supplement	Replace	N/A
10 Members subject to axial compression	Incorporate requirements for seismic resistant design		✓			
11 Members subject to combined actions			✓			
12 Connections	Incorporate requirements for seismic resistant design and several other minor amendments. Review the capacity of pins.		✓			
13 Fatigue	Clarify clause 13.1.6 Capacity factor Revise clause 13.2 Fatigue loading Clarify/correct detail category diagrams and equation 13.7.3(1)		✓			
14 Brittle fracture	Incorporate a map of isotherms for New Zealand		✓			
15 Testing of structures or elements	Incorporate acceptance criteria for strength and ductility testing for seismic applications. Expand advice on test procedures to match the *Bridge manual* section 6.6		✓			
Appendix: Elastic resistance to lateral buckling	Review the use of segment length instead of effective length throughout this appendix. Correct equation A4(1)		✓			
Appendix: Strength of stiffened web panels under combined actions	Confirm that equation B2(1) is correct		✓			
Appendix: Second order elastic analysis	Undertake a detailed review of the appendix wording to ensure that it properly reflects the intent.		✓			
Appendix: Eccentrically loaded dot trusses	Minor corrections		✓			
Appendix: Interaction curves for composite columns		✓				
Appendix: Fabrication			✓			
Appendix: Erection	Incorporation of NZS 3404 material on erection tolerances, inspection of bolted connections, and grouting at supports recommended.		✓			
Appendix: Modification of existing structures		✓				

A major supplement is required to incorporate seismic design requirements. This supplement, it is envisaged, would become a section in its own right. The asterisked sections would otherwise only require somewhat more minor but still significant supplements which would include cross-referencing to the seismic design supplement. (Refer to table E6)

Table E6: Summary table for AS 5100.6: NZS 3404 material not included in AS 5100 and recommended for inclusion if AS 5100 adopted.

NZS 3404 section	Recommendation/comment
Section 12: Seismic design Appendix B: Maximum levels of ductility demand on structural steel seismic resisting systems	Recommendation: That supplementary documentation be prepared to incorporate requirements for seismic design with appropriate cross-references also incorporated into the supplements to other sections of AS 5100.6. Comment: This is a major supplement required. Supplementary documentation can be based on NZS 3404 section 12 and appendix B. A section on seismic design is a major omission from AS 5100.6 and constitutes a 50-page section in NZS 3404
Appendix A: Referenced documents	Recommendation: That the referenced list of documents presented in AS 5100.6 clause 1.2 be extended to include standards relevant to steel bridge design and construction in New Zealand, drawing from NZS 3404 appendix A
Appendix C: Corrosion protection	Recommendation: That supplementary documentation be prepared to incorporate requirements for corrosion protection appropriate to the New Zealand environment. Comment: AS 5100 is deficient in its coverage of corrosion protection. Supplementary documentation can be based on NZS 3404 appendix C, which was developed to satisfy the requirements of the New Zealand Building Code clause B2: Durability.
Appendix K: Standard test for the evaluation of slip factor	Recommendation: When revised in the future, it is recommended that appendix J of AS 4100 be incorporated into AS 5100. Comment: NZS 3404 appendix K is the same as AS 4100 appendix J. At the present time AS 5100 references appendix J of AS 4100, but it is thought that AS 4100 is not referred to for anything else, and so it would be better for AS 5100 to incorporate appendix J avoiding the need to refer to AS 4100, a standard generally not used in New Zealand
Appendix L: Inspection of bolt tension using a torque wrench	Recommendation: Accompanying the recommendation of section 6.23.3 to incorporate requirements for the inspection of bolted connections, it is recommended that the appendix L also be incorporated as supporting 'informative' documentation.

Recommendations

Considering the collective conclusions on all parts of AS 5100 regarding their suitability for adoption it is recommended that:

- The *Bridge manual*, with adoption of the NZS 3101 (concrete) and NZS 3404 (steel) materials design codes, should be retained for bridge design in New Zealand.
- At the same time as revision of the New Zealand concrete and steel materials design codes is being considered, Transit should promote greater representation on Standards New Zealand code committees to ensure that any deficiencies in the bridge design area are more adequately covered.
- The *Bridge manual* should undergo a major revision to incorporate the sections of AS 5100 (excluding the concrete and steel materials sections) identified in this project that would enhance the present provisions. Some sections of the *Bridge manual* could make direct reference to additional material presented in AS 5100, but for other sections it might be more appropriate to revise the *Bridge manual* provisions taking into account the requirements presented in AS 5100.
- The emphasis of the next revision of the *Bridge manual* should be based on harmonisation with AS 5100; however, it is also important that other overseas bridge design standards be monitored to identify new developments in design procedures and construction materials appropriate for application in New Zealand. On some aspects of design it may be appropriate to reference or incorporate into the *Bridge manual* provisions from standards other than AS 5100.
- NZTA should form a strategic planning group comprising local bridge design and highway experts to advise on revising and maintaining the *Bridge manual* to the best international practice appropriate for New Zealand.

Abstract

The objective of this project was to investigate the practicality of adopting the AS 5100 bridge design standard for New Zealand. The significant differences and gaps between current design requirements as presented by AS 5100 and the Transit NZ *Bridge manual* and its supporting standards were identified. The project gave consideration to the New Zealand regulatory environment and identified measures that would need to be taken to enable AS 5100 to be used in New Zealand.

Although many advantages and disadvantages were identified for adopting AS 5100 for bridge design in New Zealand, it was considered that the best option was to retain the *Bridge manual* and to revise it to incorporate more of the AS 5100 material relevant to bridge design than presently adopted. The overriding consideration in reaching this conclusion was the difficulty of preparing supplementary material for AS 5100.5 and AS 5100.6 to incorporate seismic design requirements consistent with the New Zealand seismic design philosophy. There were also significant differences between the *Bridge manual* and AS 5100 approaches to traffic loads and loading combinations that have had a major impact on both construction costs and the adequacy of existing bridges, and these would be difficult to resolve and unify.

Introduction

Purpose of the proposed research

The purpose of this research was to identify the significant differences and gaps between current design requirements as presented by Australian standard AS 5100:2004 (AS 5100) for bridge design and the Transit NZ *Bridge manual* and its supporting standards. A basic assumption of this project was that the AS 5100 standard would be adopted for New Zealand practice, albeit with additional documentation that specified necessary exceptions and alternatives. The project also considered the New Zealand regulatory environment and identified measures necessary for the application of AS 5100 in New Zealand.

Transit NZ is a member of Austroads, the association of Australian and New Zealand road transport and traffic authorities, and has a policy of adopting Austroads publications when practicable and suitable for application in the New Zealand environment. As a result of CER, there has also been a move to align New Zealand and Australia standards, with many now produced as joint AS/NZS standards.

New Zealand is a small country with limited skilled technical and financial resources available for the development and maintenance of design standards. Adoption of the Australian standard for bridge design would result in a greater pool of resources being available for the development of the bridge design standard in New Zealand, and would also result in the standard being compatible with, and underpinned by, other design guidance currently being developed by Austroads in their bridge technology series of publications. It would also allow the use of bridge design software which incorporates AS 5100, thus providing efficiencies for bridge design in New Zealand.

This research builds on a previous Transfund NZ project: 'A framework for an ideal road structures design manual' (Kirkcaldie 1997). That project outlined the coverage desirable in an ideal road structures design manual and included a comparison of the 1992 Austroads Highway Bridge Design Code (the predecessor of AS 5100) with the *Bridge manual*. It concluded that an ideal road structure design manual could not be satisfactorily created from one of the documents alone but would require incorporation and significant modification of both documents together with consideration of information from other sources. This previous project provided the basis for many of the more recent *Bridge manual* amendments, which have generally increased the harmonisation with the Australian bridge design standards.

In the short term, if AS 5100 were adopted as the standard for bridge design in New Zealand, a significant effort would be required to produce supporting documentation to adapt the standard to New Zealand conditions. This is expected to apply particularly in the areas of:

- Transit procedures for selection and approval of the option for final design (bridge design statement)
- earthquake resistant design
- live loading and associated secondary loads (braking, centrifugal force)
- concrete materials design
- elastomeric bearings design
- compatibility with the New Zealand Building Act and Building Code.

In the long term, the effort involved from New Zealand to maintain the bridge design standard is expected to be reduced because it will be shared with all the Australian states.

Report format

The format of this report follows the section titles of AS 5100, and compares the content of each section with the comparable requirements presented in the *Bridge manual*. The report concludes with a section capturing those aspects of the *Bridge manual* not encompassed by AS 5100. Overall conclusions on the adequacy of AS 5100 for adoption for bridge design in New Zealand and recommendations for the way forward are given following the executive summary at the front of the report.

The numbers of the report's main sections 1 to 7 correspond to the part numbers in AS 5100, and with the exception of appendices and summaries, the main heading numbers in each section correspond to the section number in each AS 5100 part. For example, report heading number 3.4 refers to section 4 in part 3 of AS 5100 (AS 5100.3). The final main section of the report, section 8, covers the topics not included in AS 5100.

The report is published in two volumes as follows:

Volume 1: Executive summary, recommendations and parts 1 to 4.

Volume 2: Parts 5 to 8.

1 AS 5100:1: Scope and general principles

AS 5100.1 content

Table 1.1 lists the content of part 1 of AS 5100 (AS 5100.1) together with the comparable sections or clauses of the *Bridge manual*.

Table 1.1 AS 5100.1 content and comparable *Bridge manual* clauses.

AS 5100.1 content	Comparable *Bridge manual* clauses
1 Scope	Introduction
2 Application	Introduction
3 Referenced documents	References relevant to each section are listed at the end of each section
4 Definitions	2.1.2
5 Notation	3.5 – for notation used to designate loadings, otherwise notation is defined in individual clauses as the notation arises
6 Design philosophy	2.1
7 Waterways and flood design	2.3
8 Environmental impact	1.3 – but does not specify requirements
9 Geometric requirements	2.2; Appendix A
10 Road traffic barriers	2.2; Appendix B
11 Collision protection	2.2; 3.4.18; Appendix B
12 Pedestrian and bicycle path barriers	Appendix B
13 Noise barriers	Not covered
14 Drainage	4.13.3
15 Access for inspection and maintenance	1.3 – but does not specify requirements
16 Utilities	1.3; 4.13.4
17 Skew railway bridges	Outside the scope of the *Bridge manual*
18 Camber on railway bridges	Outside the scope of the *Bridge manual*
Appendix A: Matters for resolution before design commences	Not covered
Appendix B: Road barrier performance level selection method	Appendix B

1.1 Scope (section 1) and application (section 2)

1.1.1 Outline of coverage

AS 5100.1 specifies requirements for the design of the following structures:

- bridges providing support to road traffic loads, railway traffic loads, and tramways and pedestrian bridges
- other structures providing support to road or railway traffic or their loads (eg culverts, structural components related to tunnels, retaining structures, deflection walls, sign gantries)
- structures built over or adjacent to railways, or both
- modifications to existing bridge structures.

In applying the standard for structures with spans greater than 100 m, railways with speeds greater than 160 km/h, unusual or complex structures, and structures constructed from materials other than those covered (concrete and structural steel), the requirements of the standard are to be supplemented by other appropriate standards and specialist technical literature. Some clauses in the standard are noted as requiring confirmation of acceptance by the relevant authority or structure owner.

1.1.2 Variation of requirements from the *Bridge manual*

The *Bridge manual* is written explicitly to set out Transit's requirements and, compared with AS 5100.1, does not cover railway or cable supported structures, and limits its applicability to structures with spans not exceeding 100 m.

1.1.3 Suitability and actions required to enable adoption

The scope and application of AS 5100.1 encompass the scope and application of the *Bridge manual* and are intended to be even broader; therefore, no action is required regarding scope and applicability, providing the requirements of the standard are otherwise found to be appropriate for the New Zealand roading environment.

Clauses within AS 5100.1 requiring confirmation of their acceptance by the relevant authority (in this case Transit) will require review and their acceptance, or rejection, documented.

1.2 Application

See section 1.1 above.

1.3 Referenced documents

1.3.1 Outline of coverage

Section 3 of AS 5100.1 lists documents referred to in this part. These comprise standards, with one technical advisory document.

1.3.2 Variation of requirements from the *Bridge manual*

The *Bridge manual* differs from AS 5100.1 in listing numerous references at the end of each section. These comprise standards and useful technical publications, which reflect the different philosophies inherent in the two documents. In addition to the documents listed in section 3 of part 1, AS 5100.1 references technical advisory documents in several appendices to the main parts, but these only cover a limited number of topics.

1.3.3 Suitability and actions required to enable adoption

Review of other sections of this part will inevitably require additions to and some exclusions from this list of referenced documents to incorporate standards and regulations relevant to the New Zealand environment. This is expected to include, but not necessarily be limited to, the following:

- the New Zealand Building Code (NZBC)
- standards for design loadings
- the NZBC Verification method B1/VM4 foundations
- AS 1523 Elastomeric bearings for use in structures
- NZS 3101 Concrete structures standard

- NZS 3404 Steel structures standard
- NZS 3603 Timber structures standard
- AS 1720.1 Timber structures, part 1: Design methods
- AS/NZS 3845 Road safety barrier systems
- State highway geometric design manual draft (Transit New Zealand 2000)
- Highway surface drainage (Transit New Zealand 1977)

Also, the technical advisory references listed in the *Bridge manual*, section 2, relating to waterway design, and in other sections relating to numerous other topics should be added to the above list.

1.4 Definitions

1.4.1 Outline of coverage

Definitions in section 4 of AS 5100.1 are provided for the following:

- authority
- design life
- professional engineer
- reference surface
- service life
- sleeper – related to railway applications
- transom – related to railway applications.

The distinction between design life and service life in the definitions is difficult to discern. Design life is defined as the period assumed in design for which a structure or structural element is required to perform its intended purpose without replacement or major structural repairs, while service life is defined as the period over which a structure or structural element is expected to perform its function without major maintenance or structural repair.

Professional engineer is defined in terms of Australian legislation.

1.4.2 Variation of requirements from the *Bridge manual*

The definitions of design life and service life are comparable to the definition of design working life in the *Bridge manual*, which defines design working life in terms of the time to when the structure is expected to become functionally obsolete or to have become uneconomic to maintain in a condition adequate for it to perform its functional requirements. This terminology and definition in the *Bridge manual* was adopted to be consistent with AS/NZS 1170, but prior to the amendment of AS/NZS 1170 which now incorporates a definition for design working life consistent with the AS 5100.1 design life definition.

The term 'major structural repair' used by but not defined in AS 5100.1 is comparable to 'major renovation' used in the *Bridge manual*. The *Bridge manual* uses this term as a definitive interpretation of the durability requirements of the NZBC.

The *Bridge manual* also presents definitions for the serviceability and ultimate limit states. These are defined more comprehensively in AS 5100.1 under section 6 'Design philosophy'.

1.4.3 Suitability and actions required to enable adoption

For consistency, a common terminology and a common definition of design life/design working life should be adopted. The AS 5100.1/AS/NZS 1170 definition of design life/design working life is consistent with the durability requirements clause (2.1.7) of the *Bridge manual* and so can be applied with the requirements of the *Bridge manual*. However, the *Bridge manual* provides the more appropriate definition of design working life, and also treats durability explicitly, which is the preferred approach. Therefore, it is recommended that this definition and explicit specification of durability requirements be submitted to the standards committees for their consideration.

The terms: 'major structural repairs' (as used in AS 5100.1) and 'major renovation' (as used in the NZBC) need to be equated and a definition included in supplementary documentation.

In supplementary documentation, the term 'professional engineer' needs to be defined in terms consistent with New Zealand legislation.

1.5 Notation

1.5.1 Outline of coverage

Notation occurring in AS 5100.1 is defined in section 5, together with references to the clauses in which the notation occurs.

1.5.2 Variation of requirements from the *Bridge manual*

Notation is presented in the *Bridge manual* after the formulae or clauses to which it applies. No overall summary of notation is provided.

1.5.3 Suitability and actions required to enable adoption

Section 5 of AS 5100.1 is suitable for adoption without modification subject to the clauses in which the notation occurs being adopted without modification. It is debatable whether the summary method of presentation is preferable to presentation in the immediate location of the formulae or clauses.

1.6 Design philosophy

1.6.1 Outline of coverage

Section 6 of AS 5100.1 encompasses the following:

- Design is to be based on engineering principles, experimental data and experience, with attention given to a number of aspects listed in ensuring safety and performance.
- Design life – specified to be 100 years for structures covered by the standard, with elements such as deck joints and bearing having a long life compatible with that of the structure. The design life of ancillary structures such as light poles, sign structures and noise barriers may have a shorter life as specified by the authority.
- Limit states – these are defined.
- Analysis methods – linear elastic analysis is to be used unless non-linear methods are specifically implied elsewhere in the standard approved by the authority.

- Design actions (S*) – design actions are defined. An ultimate design action is taken as having a 5% probability of exceedance within the life of a structure. A serviceability design action is defined as having a 5% probability of exceedance in any one year.
- Capacity or strength – capacity or strength is defined as being as specified in the appropriate materials design part of the standard, and as being derived from the nominal capacity of the element (Ru) and the relevant capacity reduction factor (Ø) of the material. Where derived from dead loads of part or all of the structure, the capacity is to be reduced by an appropriate load factor specified in AS 5100.2.
- Verification of limit states – for the ultimate limit state (ULS), the relationship: ØRu ≥ S* is to be satisfied. For the serviceability limit state (SLS), stress, deflection, cracking or vibration levels are to satisfy limits specified in the appropriate parts of AS 5100.
- Other considerations – bridges are not designed for every possible eventuality, and there is a need to clear-span zones of potential impact or to provide appropriate redundancy, protection or robustness for impact forces that may exceed those specified.

1.6.2 Variation of requirements from the *Bridge manual*

In the area of design philosophy, the *Bridge manual* has endeavoured to align with that of AS/NZS 1170, which is expected to be taken as a benchmark by the Department of Building and Housing in administering the Building Act 2004 and requirements of the NZBC. The following variations exist:

- Design life – the *Bridge manual* does not, as it should, currently specify design lives for ancillary structures, such as bearings and deck joints. It specifies the same normal design life (100 years) as AS 5100.1.
- Design actions – in the *Bridge manual* for the ULS these have varying probabilities of exceedance which take into account the design life, importance and post-disaster function of the structure.
- Other considerations – the *Bridge manual* mentions the approaches to mitigation of accidental impact forces given in AS 5100.1, and also presents a specific requirement for all elements of the structure to be adequately interconnected to provide robustness against unanticipated extreme events.
- Durability – a durability requirement is specified in the *Bridge manual*, whereas it is implied through the design life definition in AS 5100.1.

1.6.3 Suitability and actions required to enable adoption

The design philosophy section is generally suitable for application in New Zealand; however, if AS 5100.1 were to be adopted, its philosophy should be tested with the Department of Building and Housing to ensure it meets the requirements of the NZBC. In view of the philosophical differences between AS 5100.1 and the *Bridge manual* (and by inference AS/NZS 1170), it may be expected that one standard meets with acceptance by the Department of Building and Housing and the other does not. Taking this into account, the provision of supplementary documentation addressing the following, is recommended:

- the specification of design lives for ancilliary structures
- replacement of the definition of ultimate actions with the material extracted from the *Bridge manual* (clause 2.1.3) describing the basis of derivation of design ultimate actions as applied in New Zealand

- incorporation of specific requirements in respect to durability and structural robustness corresponding to those contained within the *Bridge manual* (clauses 2.1.7 and 2.1.8 respectively).

The ultimate actions presented in the *Bridge manual* were developed based on AS/NZS 1170 which is understood to have been calibrated to a safety index following the principles set out in the International Standard ISO 2394 'General principles on reliability of structures'. With the Department of Building and Housing expected to cite AS/NZS 1170 as an acceptable solution for design loadings, this standard is expected to provide a benchmark for design loadings for the issue of building consents in New Zealand, and thus alignment with it will continue to be desirable to ensure the acceptance of designs. Adoption of the AS 5100.1 specification of ultimate actions, which is less conservative for some actions, is therefore not supported.

Similarly, inclusion of a robustness requirement that aligns with AS/NZS 1170 and an explicit durability requirement that aligns with and clarifies the NZBC is considered to be desirable to enable the passage of building consent applications through the consent process.

1.7 Waterways and flood design

1.7.1 Outline of coverage

Coverage in section 7 of AS 5100.1 is given in general terms to the following:

- Factors to be considered include:
  - span and vertical clearances required for navigation by river craft
  - serviceability requirements – frequency and duration of loss of service due to inundation
  - serviceability requirements of the surrounding land
  - serviceability requirements of the channel bed, banks and road embankment versus scour protection required
  - serviceability of the bridge under the SLS flood
  - strength and stability of the bridge under the ULS flood
  - the hydraulic capacity required of the system to avoid unacceptable afflux effects under overtopping in a ULS flood
  - the impact of any stream improvement works or the bridge and embankment in altering flood flow patterns.
- Estimation of design floods – ultimate and serviceability design floods to comply with the probabilities of exceedance specified in the design philosophy section, with theoretical estimates of flood sizes to be compared with local flood experience.
- Debris – the need to assess the amount and size of debris, the span length and clearance required to pass the debris, and to design for the hydrodynamic and impact forces imposed on the structure.
- Stream improvement works – to be considered where the natural stream course is unstable.
- The design of piers and abutments – to minimise the effects on water flow, avoid trapping debris and maintain stability under scour effects.

- Secondary structures which encompass:
  - the need, on wide floodplains, for relieving culverts or floodways
  - the design of culverts for hydraulic forces, protection against undermining, and for stabilisation of the downstream end against the effects of embankment overtopping, and the sizing and spacing of culverts for debris.
  - the protection of embankments.

Specific bridge waterway requirements are to be determined by the authority in consultation with other relevant authorities.

1.7.2 Variation of requirements from the *Bridge manual*

The *Bridge manual* is considerably more specific in its requirements for waterway and flood design, specifying:

- compliance with the Austroads publication: Waterway design – a guide to hydraulic design of bridges, culverts and floodways (Austroads 1994), except as amended
- 100 years as the minimum annual recurrence interval flood that the structure must be capable of passing without significant damage to the structure or waterway
- the minimum level of service that must be provided for the passage of traffic, including the associated freeboard allowance
- the ULS flood that the bridge must have the strength and stability to withstand
- flood estimation methods and approaches to be used
- the methods to be employed for the estimation of scour.

1.7.3 Suitability and actions required to enable adoption

AS 5100.1 sets out the general considerations, and, in that respect, is suitable for application in New Zealand. However it should be supplemented by the specific requirements of the *Bridge manual*, and the design flood events should be replaced by the *Bridge manual* requirements.

1.8 Environmental impact

1.8.1 Outline of coverage

Environmental requirements are to be determined by the authority in consultation with other authorities, but are to include the following:

- discharge of pollutants
- paint systems
- flora and fauna protection
- capture of run-off and silt traps for excavations.

1.8.2 Variation of requirements from the *Bridge manual*

The *Bridge manual* does not contain requirements related to environmental impact other than to require environmental considerations and constraints to be presented and discussed in the bridge design statement.

1.8.3 Suitability and actions required to enable adoption

The AS 5100.1 requirements are appropriate for adoption for New Zealand use.

For issues governed by national legislation and regulations, or in which there is national unanimity of approach among regional councils, Transit should develop and document requirements. For issues where there is variability in the approach adopted by regional councils, or variability in requirements around New Zealand due to variability in the environmental conditions or for other reasons, the design statement will remain the appropriate avenue for determining and endorsing approaches to be taken.

1.9 Geometric requirements

1.9.1 Outline of coverage

Section 9 of AS 5100.1 covers:

- railway bridges – to be as specified by the railway authority
- bridges over navigable waterways – to be as specified by the waterway authority
- road bridge carriageway widths – these are to be determined by the relevant authority, but based on the following:
  - provision of a consistent level of service along a highway
  - traffic lane widths provided on the bridge being no less than on the approach roadway
  - minimum specified clear widths being met for national highways (refer to the comparison with the *Bridge manual* below)
  - for other roads, the full width of the shoulders and pavement being accommodated on bridges of less than specified lengths (refer to the comparison with the *Bridge manual* below)
- edge clearances for bridges without walkways
- horizontal clearance to substructure components of bridges over roadways
- vertical clearance over roadways
- vertical and horizontal clearances of bridges over railways – to be as required by the railway authority
- superelevation and crossfall
- walkway width on road bridges
- pedestrian bridges
- pedestrian subways
- bicycle paths.

1.9.2 Variation of requirements from the *Bridge manual*

1.9.2.1 General

The variations between the AS 5100.1 and *Bridge manual* requirements are many, though the approaches are generally similar and the results not too dissimilar.

1.9.2.2 Bridge widths, and clearances between side protection and traffic lanes

The following tables 1.2 and 1.3 present comparisons of some of the requirements.

Table 1.2 compares the AS 5100.1 and *Bridge manual* requirements for minimum clear width of bridges on national highways in Australia and state highways in New Zealand. AS 5100.1 does not specify a minimum width for traffic lanes.

Table 1.2 Comparison of AS 5100.1 and Transit *Bridge manual* minimum clear bridge widths.

AS 5100.1			**Transit *Bridge manual* for 2-lane bridges**		
AADT per lane	Bridge length (m)	Minimum clear width	AADT	Bridge length (m)	Nominal carriageway width (m)
All AADT	≤20	Full carriageway width	> 4000	≤ 30	10.0
				> 30	9.4
≥1000	> 20	Width of traffic lanes + 2.4 m (= 9.4 m for 2 x 3.5 m lanes)	2000–4000	≤ 15	10.0
				> 15	9.0
< 1000	>20	Width of traffic lanes + 1.2m (= 8.2 m for 2 x 3.5 m lanes)	500 –2000	All	8.5
			<500	All	8.2

Table 1.3 compares the length of bridge requiring a full width carriageway. These are based on annual average daily traffic (AADT) 30 years ahead in both cases. In the *Bridge manual* these do not apply where the approach road is kerbed, the bridge has footpaths or the approach road shoulder width is less than the clearance required between the barrier on the bridge and the adjacent traffic lane.

Table 1.3 Length of bridge requiring a full carriageway width deck.

AS 5100.1		**Transit *Bridge manual***	
Type of road	Length of bridge (m)	Type of road	Length of bridge (m)
National highways	≤ 20 m		
Freeways/motorways	≤ 50 m	Motorway	≤ 75
Controlled access roads	≤ 50 m		
Divided highways	≤ 20 m	Divided road	≤ 30
Other roads where the expected AADT will be:		2-lane road where the expected AADT is:	
>2000		> 4000	
500 –2000	≤ 15	2000–4000	≤ 30
≤500	≤ 9	500 –2000	≤ 15
	≤ 6	< 500	≤ 9
			≤ 6

Table 1.4 compares edge clearances required between bridge deck side protection and the adjacent traffic lanes. In AS 5100.1 they apply only to bridges without walkways.

Table 1.4 Clearance between bridge side protection and the adjacent traffic lane.

AS 5100.1		**Transit *Bridge manual***		
Type of road	Clearance (mm)	Type of side protection	Type of road	Clearance (mm)
		Kerbs	Kerbed approach road	Align bridge kerb with approach kerb
			No approach road kerb	600 minimum
Low volume 2-lane roads (≤500 vehicles/day)	600	Safety barrier	Low volume 1 or 2-lane roads (AADT < 500)	600 preferred minimum 300 absolute minimum.
Medium volume 2-lane roads (500 –5000 vehicles/day)	1000		Medium volume 2-lane roads AADT 500–2000 (i) AADT 2000–4000	750 preferred minimum 600 absolute minimum 1000 preferred minimum 600 absolute minimum
High volume roads (≥ 5000 vehicles/day)	1200		High volume 2-lane roads (AADT > 4000)	1200 preferred minimum 600 absolute minimum
			Divided roads and motorways	1200 preferred minimum 600 absolute minimum

1.9.2.3 Clearance envelope to underlying roadways

AS 5100.1 does not define a horizontal clearance envelope around a roadway, leaving the road controlling authority to specify their requirements, but does list factors to be taken into consideration, while the *Bridge manual* defines a horizontal and vertical clearance envelope.

Vertical clearances specified by AS 5100.1 are as given in table 1.5. The *Bridge manual* specifies a minimum requirement of 4.9 m and a preferred requirement of 6.0 m over the carriageway which reduces over the shoulders.

Table 1.5 AS 5100.1 specified vertical clearance over roadways.

Location	**Clearance minimum (m)**
Urban and rural freeways	5.3
Main and arterial roads	5.3
Other roads	4.6*
High clearance routes	5.8
Pedestrian bridges	As set out below

*Note: Provided there is a 5.3 m clearance on an alternative road approved by the authority.

AS 5100.1 requires vertical clearances to pedestrian bridges to be:

- at least 200 mm greater than adjacent traffic bridges, but not less than 5.3 m
- 5.5 m minimum where there are no adjacent bridges
- 6.0 m minimum on designated high clearance routes.

1.9.2.4 Footpaths and cycletracks

AS 5100.1 requires a minimum footpath width of 1.8 m unless specified otherwise by the authority, and also specifies minimum gradients for stairways and ramps associated with pedestrian bridges. The corresponding *Bridge manual* requirements are:

- behind a rigid barrier: 1.00 m minimum; 1.70 m preferred
- all other situations: 1.30 m minimum; 2.00 m preferred.

For subways, AS 5100.1 specifies a clear width of 3.0 m, clear height of 2.4 m and a ramp gradient of 1:8 minimum. These are not covered in the *Bridge manual*.

AS 5100.1 also covers clear widths and ramp gradients for cycletracks, again not covered by the *Bridge manual*. These are given in tables 1.6 and 1.7.

Table 1.6 Clear width of bicycle paths on roadways.

Bicycle paths on carriageway (one-way cycling)	2.0 m minimum
Separate bicycle path (two-way cycling)	3.0 m minimum
Dual use (two-way bicycles and pedestrians)	3.0 m minimum

Table 1.7 Ramp gradient of bicycle paths on road bridges.

For ramp length up to 20 m	Maximum 1 in 8
For ramp length up to 50 m	Maximum 1 in 14

1.9.3 Suitability and actions required to enable adoption

Geometric requirements determine the width of the bridge superstructure and also, in the case of bridges over roads, the height of bridges (and thus also embankments). Consequently they have a significant impact on costs associated with bridging.

AS 5100.1 does a good job of outlining the factors to be considered in determining geometrics of the bridge deck cross-section. However, in some respects it is less specific in the actual criteria to be adopted than is the *Bridge manual* when it comes to considering the make-up of the deck cross-section and the various combinations of lane width, edge clearance, barrier form and footpaths/cycletrack.

The *Bridge manual* presents a range of geometric width criteria that have been developed to suit New Zealand conditions. Before adoption of the AS 5100.1 bridge width criteria is considered, a detailed review of these criteria and their cost implications by Transit's roading geometrics and traffic safety specialists is recommended.

In respect to vertical clearances over roads, the Austroads approach of adopting different vertical clearances dependent on the road type being crossed is not favoured. Past experience has shown that it is extremely difficult to control where trucks can travel, so a uniform vertical clearance related to the legal maximum allowable height of vehicles is to be preferred. Also over time, roads may change their function and be upgraded.

The AS 5100.1 approach of requiring a higher vertical clearance for footbridges is favoured and is also included in the *Bridge manual*. Footbridges are generally relatively light structures that do not have the robustness to withstand lateral vehicle impact on their superstructures that road bridges possess.

The AS 5100.1 provisions for footbridges, subways and cyclepaths are considered to be generally appropriate for New Zealand use, except that where cyclists are accommodated on the road carriageway (one-way cycling) there would be an increase in width above the 1.5 m wide shoulders commonly provided.

Recommendations:

- that Transit specialists review the geometric standards for the make-up of the bridge deck cross-section and consider whether the AS 5100.1 criteria might be appropriate for adoption instead of those specified by the *Bridge manual*
- that Transit retain its current criteria for road bridge vertical clearances but revise its criteria for footbridge vertical clearances to align with AS 5100.1
- that Transit adopt the AS 5100.1 criteria for footbridges, subways and cycle paths but review the width to be provided where cyclists are accommodated on the road carriageway
- that in the event of AS 5100.1 being adopted, supplementary documentation be prepared to overwrite those aspects of AS 5100.1's geometric standards not adopted and to supplement AS 5100.1 with Transit's specific requirements.

1.10 Road traffic barriers

1.10.1 Outline of coverage

Section 10 of AS 5100.1 applies to traffic barriers for new bridges and replacement traffic barriers for existing bridges, and sets out the design requirements for road traffic containment barriers on bridges.

Its coverage includes:

- the separation of footpaths from the adjacent carriageway
- principles applying to the form and properties of the traffic barrier
- acceptance criteria for bridge traffic barriers
- characterisation of various performance levels in terms of test vehicles, speed and angle of impact
- criteria for the determination of required barrier performance level
- requirements for the geometry of the barrier for parapet type barriers, post and rail type barriers
- requirements for the transition from an approach barrier to the bridge barrier and end treatments.

It is noted that kerbs are not covered in this section.

1.10.2 Variation of requirements from the *Bridge manual*

1.10.2.1 General

AS 5100.1 requires the performance level and barrier type requirements to be specified by the relevant authority, whereas the *Bridge manual* provides a risk-based procedure and lists preferred solutions as the basis for the designer to determine and recommend an appropriate solution.

1.10.2.2 Barrier form and properties principles

AS 5100.1 outlines principles to be satisfied by the form and properties of the barrier which are not spelt out in the *Bridge manual*. These include:

- performance requirements, in general terms, for the containment, deceleration, redirection and avoidance of spearing of vehicles
- capability for rapid repair
- ability to accommodate movements of the bridge structure
- harmonisation with the bridge structure and avoidance of unnecessary obstruction of view and sight distance
- being detailed to limit hydrodynamic forces and debris entrapment under inundation by floods of up to 20-year return period. (The *Bridge manual* does not permit state highway bridges to be inundated by floods of up to 20-year return period.)

1.10.2.3 Barrier performance levels

Barrier performance levels specified by AS 5100.1 and by the *Bridge manual* can be approximately equilibrated as follows:

Table 1.8 Comparison of AS 5100.1 and *Bridge manual* barrier performance levels.

AS 5100.1		***Bridge manual***	
Barrier performance level	NCHRP 350 test level	Barrier performance level	NCHRP 350 test level
No barrier		No barrier	
Low	TL 2	Performance level 3	TL 3
Regular	TL 4	Performance level 4	TL 4
Medium	TL 5	Performance level 5	TL 5
		Performance level 6	TL 6
Special		Special performance level	

At the low end of the performance scale, the *Bridge manual* sets a higher standard than does AS 5100.1. The descriptions of performance differ a little but these differences would not lead to a variation in test level.

AS 5100.1 provides a more complete description of the medium performance level 5, although its criteria are generally reflected in the *Bridge manual* risk-based procedure.

For special and performance level 6 barriers, the *Bridge manual* is similar but more quantitative in the criteria used to define these performance levels.

1.10.2.4 Barrier geometry

For parapet type barriers, the *Bridge manual* has adopted profiles from AS 3845:1999. The AS 3845 ‘F’ type barrier conforms to the barrier profile given by AS 5100.1 figure 10.6.1(A), but the AS 3845 VCB barrier is not a shape permitted by AS 5100.1. On the other hand, the AS 5100.1 figure 10.6.1(B) barrier shape is not a shape presented in AS 3845 or accepted by the *Bridge manual*.

For post and rail systems, the *Bridge manual* does not present comparable requirements for vehicle contact surface or for the setback of posts from the face of the rail. It does, however, present full details for the W section bridge guardrail standard systems, including a series of drawings of standard detailing for the system, and indicates the intended mode of behaviour. Also, for the G9 Thrie Beam system, reference is made to AS 3845, which provides full details of the system’s standard componentry.

For the transition at bridge approaches, requirements are similar but AS 5100.1 focuses more on considerations to be taken into account while the *Bridge manual* is more prescriptive on the minimum performance test level and length of approach guardrailing to be provided. On end treatments, the *Bridge manual*, in addition to the AS 5100.1 provisions, requires compliance with the NCHRP 350 test level 3 (TL3) evaluation criteria and indicates some acceptable solutions from AS 3845.

1.10.3 Suitability and actions required to enable adoption

The AS 5100.1 criteria are generally appropriate for adoption in New Zealand except that it is felt that TL3 is a more appropriate lower bound for the minimum level of side protection, where side protection is to be provided.

Retention of the *Bridge manual's* risk-based procedure for the determination of performance level is recommended as it is a more quantitative method that is relatively simple to apply.

It is not in New Zealand's interest to have a proliferation of different post and rail barrier forms as this poses difficulties for maintaining inventories of replacement parts. Transit's present approach of indicating standard non-proprietary acceptable solutions, steering designers to selection of solutions from among these, should be retained.

It is recommended that a review be undertaken to resolve whether Transit should match its requirements to AS 5100.1, or retain its current requirements. In the event of Transit retaining its current requirements, but AS 5100.1 otherwise being adopted, supplementary documentation would be needed to modify the performance level descriptions in one or two areas to match Transit's requirements and to retain the more quantified definition of performance levels 6 and special.

In the event of AS 5100.1 being adopted, it is recommended that supplementary documentation be prepared that retains:

- the *Bridge manual'*s risk-based procedure for derivation of the required performance level
- the listing of preferred acceptable non-proprietary barrier solutions
- Transit's requirements for geometric layout, end treatment and transitions
- the drawings of standard detailing for the Transit W-section bridge guardrail system.

1.11 Collision protection

1.11.1 Outline of coverage

Relevant authorities are required to make an assessment of the risk of a vehicle impacting the bridge supports, superstructure or elements above deck level and to determine the appropriate level of protection and its performance levels. The coverage of section 11 of AS 5100.1 encompasses:

- collision from traffic load
  - the set back of bridge piers from the roadway, beyond which protection by barriers is not required, is to be determined by the relevant authority
  - pedestrian bridge piers are to be protected or located to avoid collision
- collision from railway traffic

- bridges over railways are to have a clear span between abutments
- where this is not achievable, structural form and load capacity conditions to be met by the structure are specified, including requirements for pier minimum thickness and for deflection walls

- ship collision with bridge piers
  - piers are to be protected by auxiliary structures or designed to resist the impact of craft using the waterway. Alternatively, the pier may be designed for SLS impact and failure at the ULS provided the superstructure does not collapse.

1.11.2 Variation of requirements from the *Bridge manual*

In the *Bridge manual*, collision load requirements tend to focus on the design loadings rather than on the principles associated with avoiding collapse. For collision by shipping, the *Bridge manual* requirements are the same as AS 5100.1, except the latter allows pier failure provided the superstructure does not collapse.

1.11.3 Suitability and actions required to enable adoption

The requirements of section 11 of AS 5100.1 are considered suitable for adoption without modification but note that design loads for collision, specified elsewhere in AS 5100.2, are significantly greater than those currently specified in the *Bridge manual*.

1.12 Pedestrian and bicycle-path barriers

1.12.1 Outline of coverage

Section 12 of AS 5100.1 encompasses:

- the geometric requirements for handrails, including:
  - barrier heights for pedestrians and cyclists
  - spacing of balusters and their requirement to be vertical.
- pedestrian protection barriers for bridges over electrified railways – essentially as a requirement of the railway authority, but their impact on sightline should also be considered
- protection screens to prevent objects falling or being thrown from bridges, covering:
  - design options – full enclosure on pedestrian bridges, 2.4 m high solid opaque parapet walls
  - geometric properties for screens
  - the extent of such screens along a bridge over an underlying road or railway
  - design to avoid damage to the bridge structure on failure, becoming a hazard under vehicle impact, and for panels to be replaceable.

1.12.2 Variation of requirements from the *Bridge manual*

AS 5100.1 allows handrails with only vertical balusters, whereas the *Bridge manual* permits horizontal rails in situations generally of lower risk.

Requirements for handrails mounted on traffic barriers differ between AS 5100.1 and the *Bridge manual*, with AS 5100.1 focused on the security of the rail's attachment and avoidance of vehicles being speared in a collision, while the *Bridge manual*'s focus is on design loadings. Both provide requirements for the height of the barrier, with minor differences in the heights where cyclists are present.

By comparison with AS 5100.1, the *Bridge manual* does not present requirements for protection barriers for bridges over electrified railways, or to prevent objects from falling or being thrown from bridges.

The *Bridge manual* includes requirements for kerbs.

1.12.3 Suitability and actions required to enable adoption

The AS 5100.1 requirements for pedestrian and bicycle-path barriers are considered to be generally suitable for application in New Zealand. Supplementary documentation will be required to cover requirements for kerbs, and also for the option of handrails with horizontal intermediate rails, if considered desirable. However, this option could be dispensed with particularly as horizontal rails are not permitted by the NZBC. The clear spacing between vertical members should also be reviewed as the maximum of 130 mm specified by AS 5100.1 is greater than the 100 mm specified in the NZBC.

1.13 Noise barriers

1.13.1 Outline of coverage

Section 13 of AS 5100.1 specifies that noise barriers should:

- be designed so that their failure will not damage the bridge
- have connections and joints detailed so that in the event of vehicle impact, they cannot fragment, producing projectiles
- be modular so that individual panels can be replaced, and
- not be continuous across bridge expansion joints.

1.13.2 Variation of requirements from the *Bridge manual*

The *Bridge manual* does present any requirements for noise barriers.

1.13.3 Suitability and actions required to enable adoption

The AS 5100.1 requirements for noise barriers are considered suitable for application in New Zealand. They are not very extensive and consideration may be warranted as to whether they are sufficiently comprehensive.

1.14 Drainage

1.14.1 Outline of coverage

Section 14 of AS 5100.1 requires that:

- transverse and longitudinal drainage is provided by suitable crossfall and gradient
- water flowing downgrade on the approaches towards a bridge is intercepted on the approach
- short bridges, particularly those over roads or railway, do not have scuppers, but stormwater is discharged to drains at the abutments

- long bridges have drainage outlets of sufficient number and size. Outlets are rigid, ultra-violet and corrosion resistant, not less than 100 mm in least dimension and provided with cleanouts
- drainage prevents discharge against the structure, prevents erosion by the outlet discharge and does not discharge onto traffic lanes or rail corridor
- overhanging edges of deck are provided with a drip detail, continuous where possible
- the design ensures water drains from all parts of the structure, and dirt, leaves or other foreign matter is not retained
- drainage pipes passing through closed cells of a bridge are of durable material, and the cells are provided with drain holes in case of leakage or bursting.

1.14.2 Variation of requirements from the *Bridge manual*

Provisions of the *Bridge manual* not covered in AS 5100.1 include:

- direct discharge over the edge of the deck on spans wholly over water is allowed unless there is a particular reason for not doing so. Otherwise stormwater is to be collected and specific provision made for its disposal. Stomwater drains and pipes are to be self-cleaning wherever possible
- piped drainage systems are to be designed for a 20-year return period rainfall event and advice is provided on design references
- sumps are to be positioned where they will not affect traffic ride and detailed to provide for future bridge deck resurfacing.
- deck expansion joints are required to be watertight unless specific provision is made to collect and dispose of water passing through them.

1.14.3 Suitability and actions required to enable adoption

The AS 5100.1 requirements are suitable for adoption for use in New Zealand. However, the *Bridge manual* requirements largely complement those of AS 5100.1 with little duplication and should be retained and included through supplementary documentation.

1.15 Access for inspection and maintenance

1.15.1 Outline of coverage

Section 15 of AS 5100.1 requires provision to be made for access for inspection and maintenance, and for that provision to facilitate safe work practice in terms of health and safety legislation.

1.15.2 Variation of requirements from the *Bridge manual*

The *Bridge manual* goes no further than to identify access for inspection and maintenance as a factor that influences the design, and to be addressed in the design statement.

1.15.3 Suitability and actions required to enable adoption

The AS 5100.1 requirements are suitable for adoption and use in New Zealand.

1.16 Utilities

1.16.1 Outline of coverage

Section 16 of AS 5100.1 is relatively general, requiring:

- provision to be made for the attachment of utilities as permitted by the authority
- the location and method of attachment to be subject to the approval of the authority and to be fabricated from durable materials
- the utility to be constructed of durable materials to prevent leakage into, or onto the structure.

1.16.2 Variation of requirements from the *Bridge manual*

Additionally, the *Bridge manual* requires:

- network utility operators to be advised of the extent and direction of movements at bridge expansion joints due both to length changes and seismic acceleration
- designers to consider the possibility of bridge overloading due to leakage or rupture of pipes carrying fluids inside a box girder, and for adequate drainage to be provided
- compliance with special conditions that apply to the installation of pipelines carrying flammable fluids. Such pipelines are precluded from being carried inside box girders.

1.16.3 Suitability and actions required to enable adoption

The AS 5100.1 requirements are suitable for adoption for use in New Zealand. However, the *Bridge manual* requirements largely complement the requirements of AS 5100.1 and should be retained and included through supplementary documentation.

1.17 Skew railway bridges (section 17) and camber on railway bridges (section 18)

Sections 17 and 18 of AS 5100.1 are not relevant to highway bridges and thus have not been reviewed.

1.18 Appendix A: Matters for resolution before design commences

1.18.1 Outline of coverage

Appendix A of AS 5100.1 lists all clauses throughout the AS 5100.1 standard requiring confirmation by the relevant authority or owner of the bridge or associated structure before commencement of the design process.

1.18.2 Suitability and actions required to enable adoption

A review of all of these clauses is required and Transit's requirements set out in supplementary documentation. The fact that there are 32 separate items in section 1 alone to be resolved 'by the authority' indicates the need for 'the authority' to maintain its own design manual (such as a modified *Bridge manual*), even if AS 5100.1 were adopted by Transit.

1.19 Appendix B: Road barrier performance level selection method

1.19.1 Outline of coverage

Appendix B of AS 5100.1 presents a procedure for assisting in the selection of the appropriate performance level for road traffic barriers for the more common types of bridge site risk parameters such as traffic volume, alignment and gradient of the road, height of the bridge and conditions under the bridge.

1.19.2 Variation of requirements from the *Bridge manual*

This procedure is very similar to that presented in the *Bridge manual*, but with some differences. Both procedures rely on the calculation of an adjusted AADT value through the application of factors for road type, grade, curvature of the alignment, and height of the structure and under structure land use. Then the determination of barrier performance level from graphs, for various speed thresholds, of adjusted AADT plotted against percentage commercial vehicles for various barrier offsets.

AS 5100.1 provides definitions of the factors that, in the case of the road type factor and the height and under structure land use factor, are a little more complete and clearer to interpret. However, in its treatment of water depth in relation to the height and under structure factor, clarification would be beneficial. AS 5100.1 provides good guidance on the derivation of the percentage of commercial vehicles that is lacking in the *Bridge manual*.

The following are two significant differences in the factors applied:

- road type factor – both standards adopt road type factors of:
  - 1.0 for divided roads, or undivided roads with five or more lanes
  - 2.0 for one-way traffic
- but differ for two-way undivided traffic with four or fewer lanes, where
  - AS 5100.1 adopts a constant factor equal to 1.5
  - the *Bridge manual* ramps the factor down from 1.45 at 60 km/h to 1.15 at 110 km/h design speed
- curvature factor – in a plot of CU (curvature factor, on the vertical axis) to radius of curvature (on the horizontal axis) the AS 5100.1 curve is positioned considerably to the left of the *Bridge manual* curve, as depicted in figure 1.1 below. To highlight the differences, table 1.9 presents the curvature factor derived from the two standards for a few example radii of curvature.

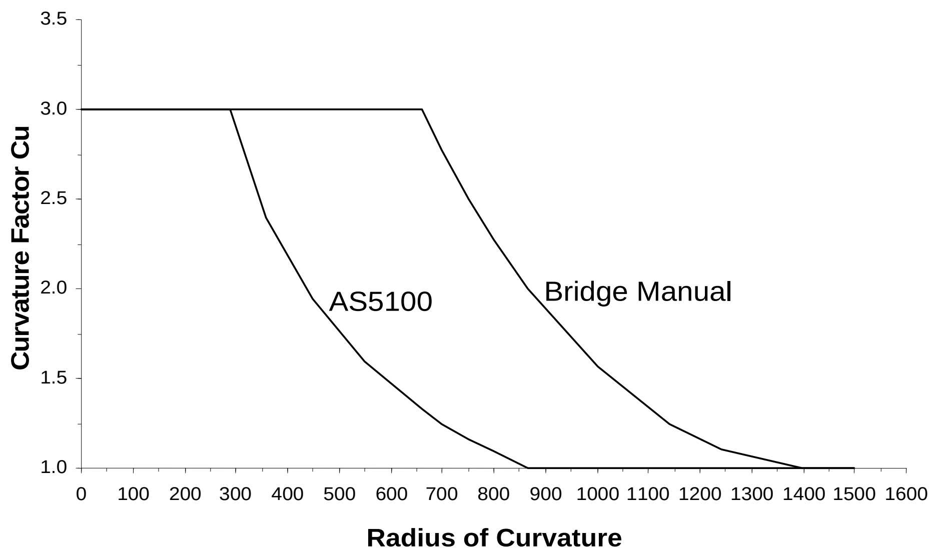


Figure 1.1 Comparison of AS 5100.1 and *Bridge manual* curvature factors.

Table 1.9 Comparison of AS 5100.1 and *Bridge manual* curvature factors for some example radii of curvature.

Example radii of curvature (m)	AS 5100.1 curvature factor	*Bridge manual* curvature factor
290	3.0	3.0
660	1.33	3.0
870	1.0	2.0
1400	1.0	1.0

As the barrier performance levels are equivalent between the two standards except at the low end, it can be seen that AS 5100.1 could require a higher barrier performance level for two-way undivided traffic flow, but a lower barrier performance level based on curvature of the road alignment.

The *Bridge manual* flow diagram for the selection procedure, extends the AS 5100.1 procedure to consider barrier requirements and the need for separate footpaths when pedestrians are present.

As noted in section 1.10, AS 5100.1 does not include a barrier performance level corresponding to NCHRP test level 6, whereas the *Bridge manual* does. Thus the specification of criteria for special performance level barriers differs somewhat. The AS 5100.1 test criteria for special performance barriers, in setting a speed of 100 km/h for the 44-tonne articulated van test vehicle, sets a higher standard than the *Bridge manual* which adopts 80 km/h as the test speed.

1.19.3 Suitability and action required to enable adoption

Overall, the AS 5100.1 road barrier performance selection method is suitable for application in New Zealand and offers some improvements over the *Bridge manual* method. However, a review is required of the appropriateness of the AS 5100.1 road type and curvature factors for New Zealand conditions. If the current *Bridge manual* factors are to be retained, this will require supplementary documentation. Retention or otherwise of the current *Bridge manual* criteria for performance levels 6 and special has been discussed in section 1.10, and if retained these would also need to be incorporated through supplementary documentation.

2 AS 5100.2: Design loads

AS 5100.2 content

Table 2.1 lists the content of part 2 of AS 5100 (AS 5100.2) together with the comparable sections or clauses of the *Bridge manual*.

Table 2.1 AS 5100.2 content and comparable *Bridge manual* clauses.

AS 5100.2 content		Comparable *Bridge manual* clauses	
1	Scope and general	3.1	Introduction
2	Referenced documents	3.6	References
3	Definitions	2.1.2	Definition of terms
4	Notation	3.5 –	for notation used to designate loadings, otherwise notation is defined in individual clauses as the notation arises
5	Dead loads	3.4.1 3.4.2	Dead load Superimposed dead load
6	Road traffic	3.2 3.3	Traffic loads –gravity effects Traffic loads – horizontal effects
7	Pedestrian and bicycle-path load	3.4.14	Loads on footpaths and cycle tracks
8	Railway traffic		
9	Minimum lateral restraint capacity	2.1.8	Structural robustness
10	Collision loads	3.4.18	Collision loads
11	Kerb and barrier design loads and other requirements for road traffic bridges	B6	Side protection design criteria
12	Dynamic behaviour	3.4.15	Vibration
13	Earth pressure	3.4.12	Earth loads
14	Earthquake forces	3.4.3 Section 5	Earthquake Earthquake resistant design
15	Forces resulting from water flow	2.1.3 2.3 3.4.8	Basis of design Waterway design Water pressure
16	Wind loads	2.1.3 3.4.5	Basis of design Wind
17	Thermal effects	3.4.6	Temperature effects
18	Shrinkage, creep and prestress effects	3.4.4 3.4.17	Shortening Forces locked-in by the erection sequence
19	Differential movement of supports	3.4.16	Settlement, subsidence and ground deformation
20	Forces from bearings	3.4.4	Shortening
21	Construction forces and effects	3.4.7 3.4.17	Construction loads Forces locked-in by the erection sequence
22	Load combinations	3.5	Combination of load effects
23	Road signs and lighting structures		
24	Noise barriers		
Appendix A: Design loads for medium and special performance level barriers		B6	Side protection design criteria

2.1 Scope and general

2.1.1 Outline of coverage

AS 5100.2 sets out the minimum design loads, forces and load effects for road, railway, pedestrian and bicycle bridges and associated structures.

The design loads and forces are to be considered as acting in combinations as set out in section 22 of AS 5100.2. Any other forces that may act, and their combination with other loads, in addition to those specified, are also to be considered in a manner consistent with the principles set out in AS 5100.2.

A range of design load information is specified to be presented on the front sheet of the bridge drawings.

2.1.2 Variation of requirements from the *Bridge manual*

The *Bridge manual* does not specify any comparable requirements for loads other than those presented in the manual for consideration, or for design load information to be presented on the drawings.

2.1.3 Suitability and actions required to enable adoption

The requirement to present design loading information on the drawings is supported, as this information is valuable if work is undertaken on the bridge in future. Further information that should also be considered for presentation on the drawings includes:

- foundation-bearing capacity
- material characteristic strength and properties (eg concrete compressive strength f'_c, steel yield strength f_y) and the steel material standard.

Section 1 of AS 5100.2 is suitable for application in New Zealand as is, but could benefit from having the list of information to be presented on the drawings extended as suggested above.

2.2 Referenced documents

2.2.1 Outline of coverage

Section 2 lists documents referred to by AS 5100.2.

2.2.2 Variation of requirements from the *Bridge manual*

No requirements are specified in this section.

2.2.3 Suitability and actions required to enable adoption

If AS 5100.2 were adopted, additions and possibly some exclusions would need to be made to this list of reference documents to incorporate documents relevant to New Zealand. Additions would be expected to include the documents referenced in the *Bridge manual* section 3.6. and also NZS 1170.5 'Structural design actions, part 5: Earthquake actions'.

2.3 Definitions

2.3.1 Outline of coverage

Section 3 of AS 5100.2 states that the definitions of AS 5100.1 apply.

Section 1.4 of this report comments on variation from the *Bridge manual* and suitability for application in New Zealand.

2.4 Notation

2.4.1 Outline of coverage

Notation occurring in AS 5100.2 is defined in section 4, together with references to the clauses in which the notation occurs.

2.4.2 Variation of requirements from the *Bridge manual*

No requirements are specified by this section.

2.4.3 Suitability and actions required to enable adoption

Section 4 of AS 5100.2 is suitable for adoption without modification, subject to clauses in which the notation occurs being adopted without modification.

2.5 Dead loads

2.5.1 Outline of coverage

Section 5 of AS 5100.2 covers permanent dead loads, superimposed dead loads, soil loads on retaining walls and buried structures, and railway ballast and track loads.

Load factors are specified for both the ULS and the SLS, and in the case of the ULS as to whether the load acts to reduce safety or increase safety.

2.5.2 Variation of requirements from the *Bridge manual*

AS 5100.2 includes non-structural elements unlikely to vary during the use of the structure, such as parapets and kerbs within the dead load, whereas the *Bridge manual* treats these as superimposed dead load.

The AS 5100.2 approach applies load factors to the dead load which differ depending on whether the weight of a part, or load on a part, of the structure reduces or increases safety. This is also covered in the *Bridge manual* but perhaps is not as clearly expressed by the requirement that a permanent load, at the SLS, is to be replaced by 0.9 x permanent load, and at the ultimate state by the permanent load /j, where j is the load factor outside the bracket applied to all permanent loads.

There is significant difference in the load factors applied to dead load and superimposed dead load between AS 5100.2 and the *Bridge manual*. For the general or common cases the load factors adopted by the two standards are as given in table 2.2:

Table 2.2 Dead load and superimposed dead load load factors.

AS 5100.2				***Bridge manual***		
Load	**ULS load factor**		**SLS load factor**	**Load**	**ULS load factor**	**SLS load factor**
	Reduces safety	**Increases safety**				
Dead load, steel construction	1.1	0.9	1.0	Dead load	Varies 0.8* – 1.35	1.0
Dead load, concrete construction	1.2	0.85	1.0			
Superimposed dead load	2.0	0.7	1.3	Superimposed dead load	Varies 0.8* – 1.35	1.0

*Note: 0.8 applies when vertical earthquake, reducing the effect of gravity, results in a more severe situation. Otherwise the load factor varies 1.0 –1.35 depending on the load combination.

AS 5100.2 does not specify any minimum allowances to be made for surfacing or services, whereas, regardless of whether a bridge is be surfaced immediately or not, the *Bridge manual* requires an allowance of 1.5 kN/m^2 to be made for surfacing. The *Bridge manual* also requires a minimum allowance of 0.25 kN/m^2 over the full width of the bridge deck to be made for services.

AS 5100.2 specifies a design loading for railway ballast and track loads, which is not covered or relevant to the *Bridge manual* as it does not consider railway bridges.

2.5.3 Suitability and actions required to enable adoption

The AS 5100.2 approach of applying a reduction load factor at the ULS where the load increases safety is considered to be appropriate (eg where axial load increases the flexural capacity of a reinforced concrete member subjected to combined compression and flexure.) It is also an approach adopted by AS/NZS 1170. However, the ULS load factors differ significantly from those adopted by the *Bridge manual*, with those for dead load being significantly lower, while that for superimposed live load is significantly higher. The *Bridge manual* load factors for dead load generally align reasonably with AS/NZS 1170.

Before adoption of the AS 5100.2 criteria, a detailed review of what load factors are appropriate in conjunction with a review of load combinations is recommended. This recommendation applies not only to dead load and superimposed dead load, but also to all the other load types. This is necessary to ensure alignment with the safety index adopted by the NZBC and its supporting verification methods and approved documents.

Section 5 in AS 5100.2 includes specification of how soil loads on retaining walls and buried structures are to be derived that would be more appropriately located in section 13. It specifies load factors to be applied to soil densities and draws on AS 4678 'Earth-retaining structures' for the derivation of soil loads. AS 4678 applies material uncertainty factors (equivalent to strength reduction factors) in the derivation of design values for the internal friction angle, Ø, and cohesion, c, which is considered to be appropriate, but these factors are the same regardless of how these material properties are assessed, which is not a good approach. However, the AS 5100.2 provisions are an improvement on those of the *Bridge manual*.

2.6 Road traffic

2.6.1 Outline of coverage

Section 6 of AS 5100.2 presents several load models that simulate the effects of road vehicles, singly or in groups. The design loads encompass:

- gravitational live loading
- the superimposed dynamic effects due to vehicle – structure interaction
- horizontal centrifugal forces and braking forces.

Section 6 also covers:

- the number of traffic lanes to be designed
- the reduction in lane loading when multiple lanes are loaded
- a design load and spectrum for fatigue effects
- load factors to be applied for the ULS and SLS
- the distribution of traffic loads through fill.

2.6.2 Variation of requirements from the *Bridge manual*

The design traffic loading specified in AS 5100.2 differs significantly from that of the *Bridge manual* in almost every respect.

2.6.2.1 Design loading configurations

The AS 5100.2 normal design traffic load comprises the following, each considered separately:

- the W80 wheel load, which comprises an 80 kN load applied over a contact area 400 mm wide x 250 mm long anywhere on the road surface (refer to figure 2.1)
- the A160 axle load comprising two W80 wheels spaced 2.0 m apart between the centres of the wheel contact areas (refer to figure 2.1)
- the M1600 moving load comprising the combination of axle group and lane uniformly distributed loads (UDLs) illustrated in figure 2.2. The lane width is taken as 3.2 m. The lane UDL is continuous or discontinuous as may be necessary to produce the most adverse effect, and the truck variable length is similarly to be determined so as to produce the most adverse effect
- the S1600 stationary load comprising the combination of axle group and lane UDLs illustrated in figure 2.3, applied in a similar fashion to the M1600 load.

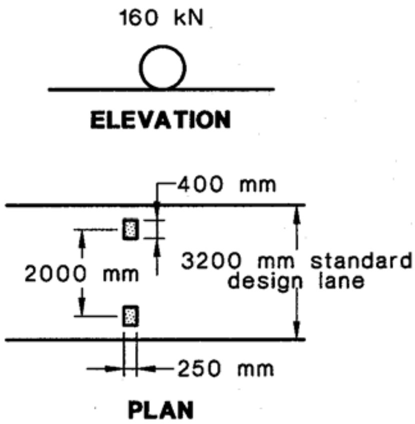


Figure 2.1 AS 5100.2 W80 wheel load and A160 axle load configurations.

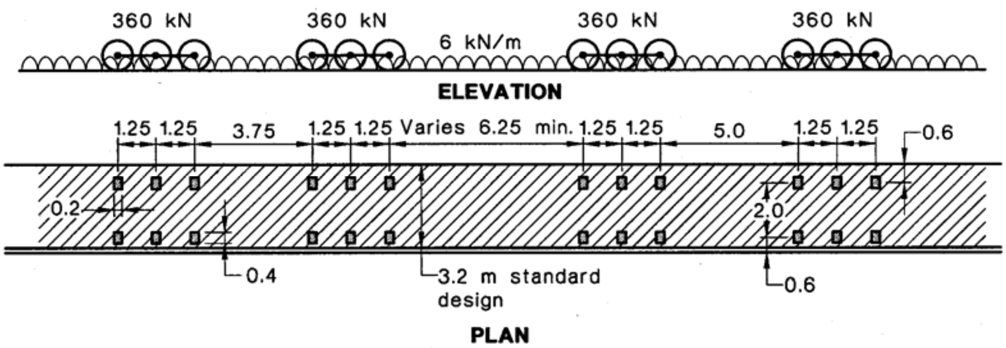


Figure 2.2 AS 5100.2 M1600 moving traffic load configuration.

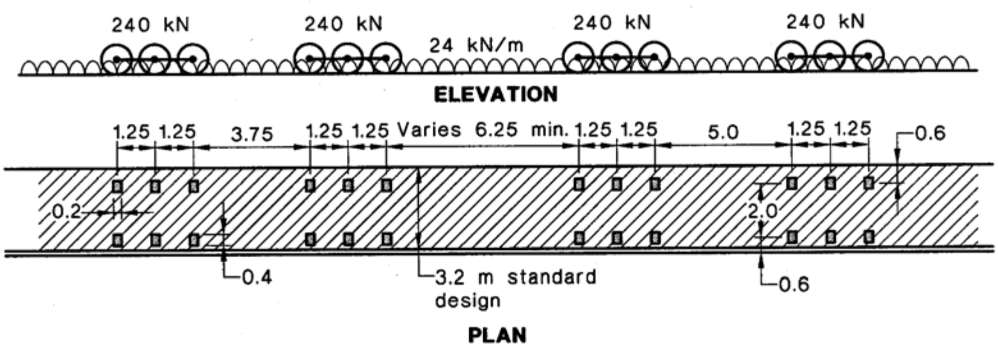


Figure 2.3 AS 5100.2 S1600 stationary traffic load configuration.

In addition, where required by the authority, bridges are to be designed for heavy load platforms (HLP). There are two forms for these, the HLP 320 load and the HLP 400 load, as illustrated in figure 2.4:

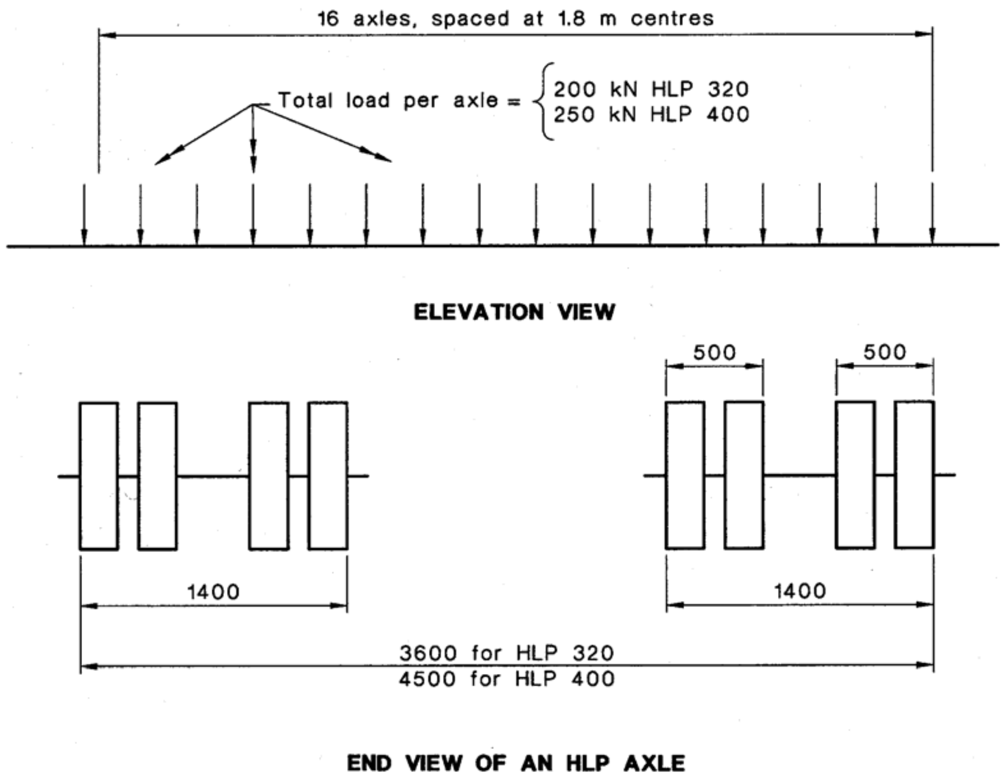


Figure 2.4 AS 5100.2 heavy load platform configurations.

These are made up and applied as follows:

- 16 rows of axles spaced at 1.8 m centres
- total load per axle: 200 kN for the HLP 320 and 250 kN for the HLP 400
- eight tyres per axle row
- overall width of axles: 3.6 m for the HLP 320 and 4.5 m for the HLP 400
- the tyre contact area is taken as 500 mm wide x 200 mm long for each set of dual wheels
- tyre contact areas are centred 250 mm and 1150 mm from each end of each axle
- for continuous bridges, the load is to be considered as separated into two groups of eight axles each with a central gap of between 6 m and 15 m, chosen to give the most adverse effect.

By comparison, the *Bridge manual* design traffic loadings, of which there are two, the HN loading and the HO loading, are much simpler, comprising two axles at a constant spacing of 5 m applied in conjunction with a uniformly distributed lane loading over a lane width of 3.0 m. These design loadings are illustrated in figure 2.5.

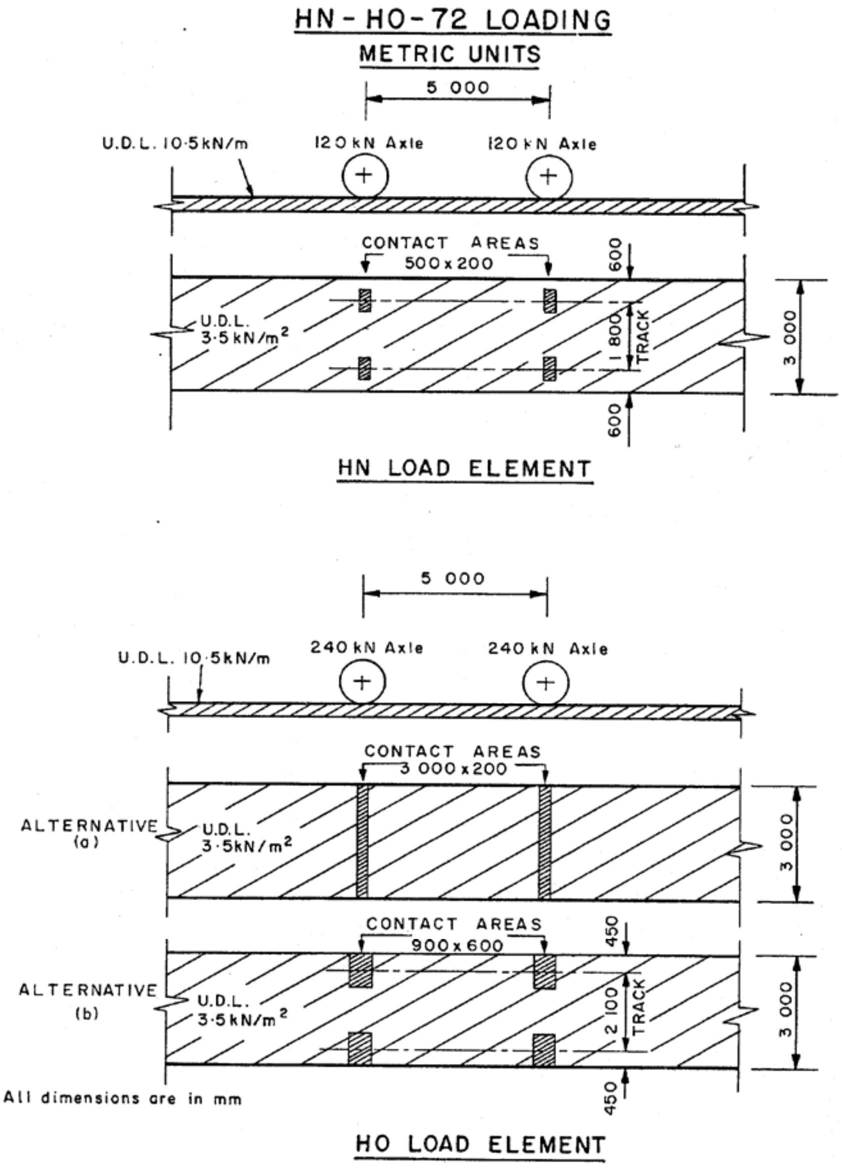


Figure 2.5 ***Bridge manual* HN and HO loading configurations.**

2.6.2.2 Number of traffic lanes in the bridge cross-section

AS 5100.2 defines the standard design lane width as 3.2 m with the number of design lanes calculated as:

n = b/3.2 (rounded down to the next integer)

where:

n = the number of lanes

b = width between traffic barriers, in metres

These lanes are to be positioned laterally on the bridge to produce the most adverse effect.

The *Bridge manual*, on the other hand, defines the roadway as the zone between the face of kerbs, guardrail or other barrier, including shoulders and cycletrack at the same level as the carriageway, and divides the roadway into equal width design load lanes with the number of lanes determined as set out in table 2.3.

Table 2.3 *Bridge manual* derivation of number of load lanes.

Width of roadway	Number of load lanes
Less than 6.0 m	1
6.0 m but less than 9.7 m	2
9.7 m but less than 13.4 m	3
13.4 m but less than 17.1 m	4
17.1 m but less than 20.8 m	5

This results in load lane widths of up to 6.0 m but generally varying from 3.0 m up to 4.85 m for other than single-lane bridges.

2.6.2.3 Factors for more than one lane loaded

When more than one lane is loaded, AS 5100.2 applies reduction factors to the loads in the additional lanes as set out in table 2.4. The *Bridge manual's* simpler approach is to apply a reduction factor to the total traffic live load when more than one lane is loaded, as given in table 2.5.

Table 2.4 AS 5100.2 accompanying lane factors.

Standard design lane number, n	Accompanying lane factor
1 lane loaded	1.0
2 lanes loaded	1.0 for the first lane, and 0.8 for the second lane
3 or more lanes loaded	1.0 for the first lane 0.8 for the second lane 0.4 for the third and subsequent lanes

Notes:
First lane – the loaded lane giving the largest effect
Second lane – the loaded lane giving the second largest effect
Third lane – the loaded lane giving the third largest effect

Table 2.5 *Bridge manual* reduction factors for multiple lanes loaded.

Number of lanes loaded	Reduction factor
1	1.0
2	0.9
3	0.8
4	0.7
5	0.6
6 or more	0.55

2.6.2.4 Dynamic load allowance

AS 5100.2 has adopted the recently revised North American approach of applying constant factors for dynamic load allowance, which are independent of the bridge length or period of vibration. The factor is applied to the total load, however, and not just the truck element. These factors are given in table 2.6.

Table 2.6 AS 5100.2 dynamic load allowance factors.

Loading (i)	Dynamic load allowance (α)
W80 wheel load	0.4
A160 axle load	0.4
M1600 tri-axle group (refer Note (ii))	0.35
M1600 load (refer Note (ii))	0.3
S1600 load (refer Note (ii))	0
HLP loading	0.1

Notes:

(i) Dynamic load allowance is not required for centrifugal forces, braking forces or pedestrian loads

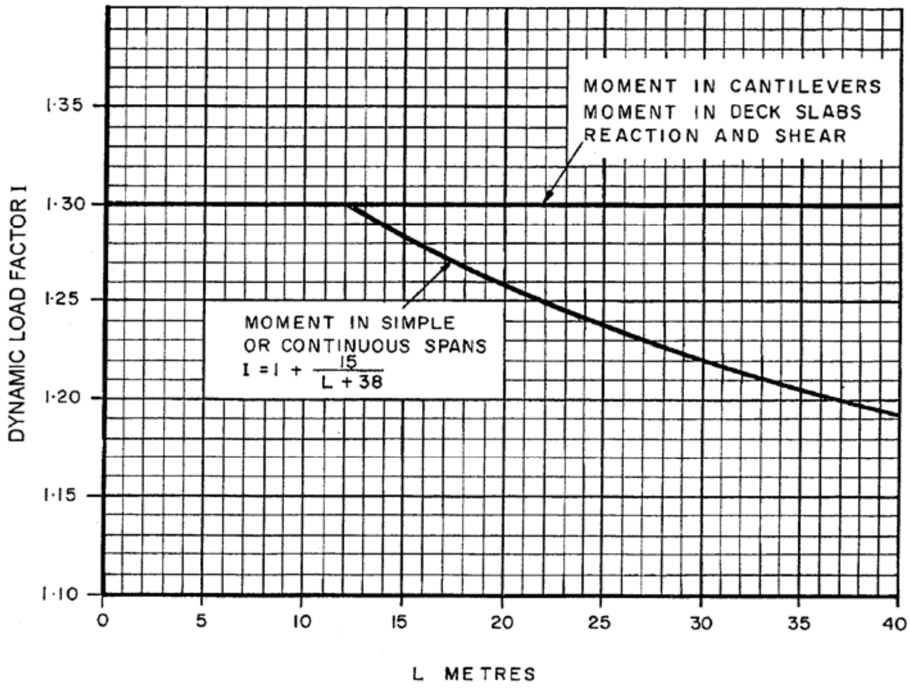
(ii) Dynamic load allowance includes the UDL component of the traffic load

The dynamic load allowance is to be considered acting both downwards and upwards.

For parts of the structure below ground level, the dynamic load allowance factor is reduced linearly from the factor at ground surface tabulated above to 0 at 2.0 m or greater below ground surface.

For buried structures such as culverts the dynamic load allowance is reduced linearly from the factor at ground surface tabulated above to 0.1 at 2.0 m or greater below ground surface.

The *Bridge manual* considers dynamic loading only as an additive to the static loading by factoring the static loading effects on a structure above ground by a dynamic load factor derived from figure 2.6. Unlike the AS 5100.2 approach, this factor, for moment, is a function of span length. The dynamic load factor is also applied to the top slab of buried culvert type structures but is reduced with depth of fill over the slab from the above ground value at ground surface to 1.0 at a depth of 1.0 m.



Note: L is the span length for positive moment and the average of the adjacent span lengths for negative moment

Figure 2.6 ***Bridge manual*** **dynamic load factor for elements above ground.**

2.6.2.5 Centrifugal forces

Both AS 5100.2 and the *Bridge manual* specify the design centrifugal force as a proportion of the design moving load acting on the bridge deck, with the lanes loaded reduction factors applied but not the dynamic load allowance. AS 5100 specifies this load to act at the level of the deck, while the *Bridge manual* specifies it to act 2 m above the road surface level. The centrifugal loads specified by the two documents are essentially the same, but AS 5100.2 places an upper bound on the force of $\leq (0.35 + \theta)W_c$, where W_c is the load due to multiple lanes of the M1600 load on the length being considered, and θ is the road super elevation expressed as a ratio (ie 4% super elevation is expressed as 0.04), a limit unlikely to ever govern.

2.6.2.6 Braking forces

AS 5100.2 specifies the braking force to be taken as the more adverse of the following two cases:

Single vehicle stopping:

$F_{BS} = 0.45W_{BS}$; 200 kN < F_{BS} < 720 kN;

where:

F_{BS} = braking force applied by a single vehicle

W_{BS} = load due to a single lane of the M1600 moving traffic load for the length under consideration, without dynamic load allowance.

Multi-lane moving traffic stream stopping:

$$F_{BM} = 0.15W_{BM}$$

where:

F_{BM} =	braking force applied by multiple vehicles
W_{BM} =	load due to multiple lanes of M1600 moving traffic load heading in a single direction, adjusted by the accompanying lane factors appropriate to the number of lanes included, for the length under consideration, without dynamic load allowance.

In comparison, the *Bridge manual* specifies the following:

For local effects, a horizontal longitudinal force equal to 70% of an HN axle load applied across the width of any loaded lane at any position on the deck surface, representing a skidding axle.

For effects on the bridge as a whole, a horizontal longitudinal force applied in each section of the bridge superstructure between expansion joints equal to the greater of:

- two skidding axles as above
- 10% of the live load applied to the section of superstructure in lanes heading in the same direction.

The *Bridge manual* is not clear on how the dynamic load factor is to be treated when determining braking forces, and so it is assumed that this factor is not included. On this basis, AS 1500 specifies a more severe design braking load for the bridge as a whole, except on short bridge sections where the two skidding axles could be more severe.

2.6.2.7 Fatigue loading

AS 5100.2 specifies a design fatigue loading, which is to be taken as the more severe of:

- 70% of the effects of a single A160 axle load with dynamic load allowance
- 70% of the effects of a single M1600 moving traffic load vehicle without the UDL but with dynamic load allowance.

Each is to be applied with a load factor of 1.0 in the design lane that maximises the fatigue effects for the component under consideration.

The number of stress cycles to be considered for each case respectively is:

- (current no. of heavy vehicles per lane per day) x 4 x 10^4 x (route factor)
- (current no. of heavy vehicles per lane per day) x 2 x 10^4 x $L^{-0.5}$ x (route factor)

where the route factor is to be taken as:

• for principal interstate freeways and highways	1.0
• for urban freeways	0.7
• for other rural routes	0.5
• for urban roads other than freeways	0.3

and L is the effective span in metres taken as the actual span length for positive moments, and the average of the adjacent span lengths for negative moments.

The *Bridge manual*, while requiring fatigue to be considered, does not present a standard fatigue load spectrum for New Zealand conditions. Use of the BS 5400: Part 10 Standard fatigue load spectrum is allowed but is acknowledged to result in a somewhat conservative outcome.

2.6.2.8 Load factors

There is considerable difference between AS 5100.2 and the *Bridge manual* load factors applied to the design traffic live loads. These are summarised in table 2.7 for the load combination cases usually dominant in design.

Table 2.7 Comparison of AS 5100.2 and *Bridge manual* load factors.

Traffic load	**Limit state**	
	Ultimate	**Serviceability**
AS 5100.2:		
W80 wheel load	1.8	1.0
A160 axle load	1.8	1.0
M1600 moving traffic load	1.8	1.0
S1600 stationary traffic load	1.8	1.0
Heavy load platform	1.5	1.0
Bridge manual:		
Normal live load (eg HN-HN)	2.255	1.35
Overload (eg HN-HO)	1.485	1.0

2.6.2.9 Deflection/vibration

AS 5100.2 requires the deflection limits of a road bridge for serviceability to be appropriate to the structure and its intended use, the nature of the loading and the elements supporting it. Not withstanding this requirement, the deflection for the SLS under M1600 moving traffic load without UDL, plus dynamic load allowance, placed in each lane with multiple lanes loaded reduction factors applied, is not to be greater than 1/600 of the span or 1/300 of the cantilever projection, as applicable. In addition, deflections are not to infringe clearance envelopes, hog deflection is not to exceed 1/300 of the span, and no sag deflection is to occur under permanent load.

The *Bridge manual*, on the other hand, does not specify deflection limits but requires structures to be checked for their vibrational response. For bridges carrying significant pedestrian or cycle traffic, the maximum vertical velocity during a cycle of vibration is not to exceed 0.055 m/sec under the two 120 kN axles of an HN load element.

2.6.2.10 Distribution of traffic loads through fill

AS 5100.2 specifies a method for the distribution of SM1600 design loads through fills. It fails to define the SM1600 loading, which is assumed to refer to either the M1600 or S1600 loading. There are no similar criteria presented in the *Bridge manual*.

2.6.3 Suitability and actions required to enable adoption

Figures 2.7 to 2.10 provide an approximate comparison of the design traffic live loadings specified by AS 5100.2 and the *Bridge manual* for the ULS and SLS, for two lanes loaded, with dynamic load allowance and multiple lanes loaded factors included. (The approximation is that the lack of coincidence of the points of maximum moment in lanes heading in opposite direction, and the reversed orientation of the M1600 truck in the second lane has been ignored. For the AS 5100.2, M1600 and S1600 loads the graphs are of the effect of the load on two lanes heading in the same direction.)

Except at span lengths approaching 100 m, where the S1600 loading produces the highest shear, the M1600 is the dominant design loading and is approximately twice the design loading currently adopted in the *Bridge manual* for spans greater than 20 m. For spans of less than 20 m it is still significantly higher although less than twice the *Bridge manual* design loading.

Adoption of the AS 5100.2 design traffic live loading, as a significantly heavier loading, would have significant implications for the construction cost of new bridges and require the development of policy for the management of the load capacity of existing bridges. The AS 5100.2 A160 axle loading is 1.33 times higher than the *Bridge manual* HN axle loading.

In AS 5100.2, in view of the dominance of the M1600 loading, the need for the standard to specify the other design loadings (S1600, HLP 320 and HLP 400) and for designers to consider them is questionable.

A design traffic loading is usually intended to be a simulation of the effects of traffic on a structure. The AS 5100.2, M1600 and S1600 design loadings, with their unsymmetrical arrangement of varying and variable axle group spacings, are unnecessarily complicated simulations of design loading that would add considerably to the modelling and analysis effort involved in design. Much simpler design loadings, such as those of the *Bridge manual* HN and HO loadings, are expected to be adequate and are preferred. The AS 5100.2 approach to applying multiple lanes loaded reduction factors to individual lanes is similarly more complicated than the *Bridge manual* approach, and again the justification for this added complexity is questionable.

It is not considered appropriate at present to adopt the AS 5100.2 design traffic live loads. A review has recently been undertaken of the design traffic live loadings appropriate for use in New Zealand, and revisions have been made to the design live loading. However, this revision is currently subject to a debate involving NZTA and other parties. It is recommended that New Zealand retain its current design traffic live loading until either the policy on heavy vehicle limits changes or dedicated extra heavy vehicle corridors are formulated and implemented.

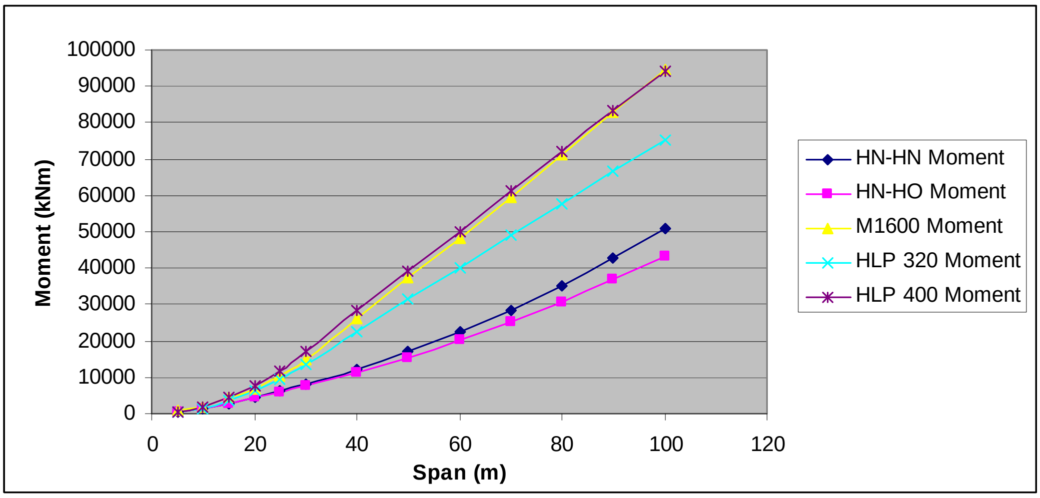


Figure 2.7 Serviceability limit state live load moments for two lanes loaded.

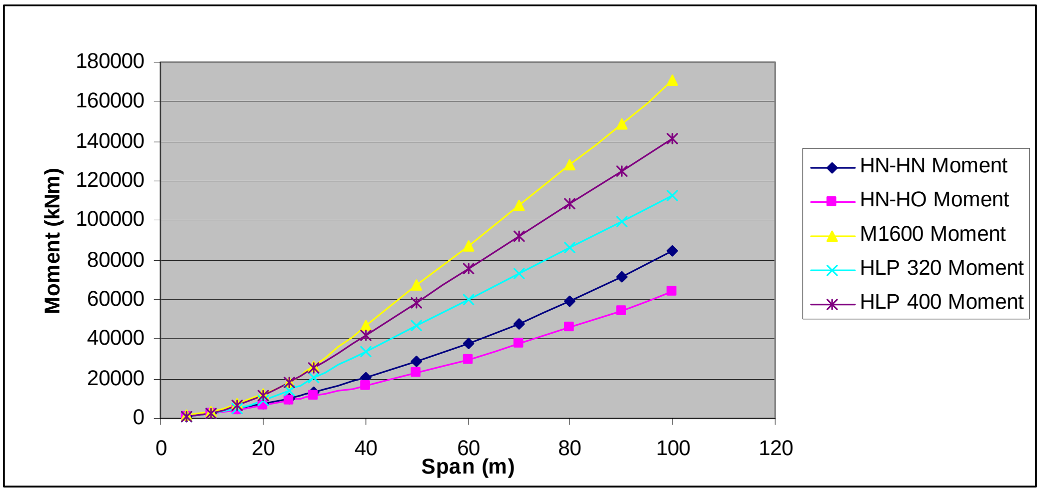


Figure 2.8 Ultimate limit state live load moments for two lanes loaded.

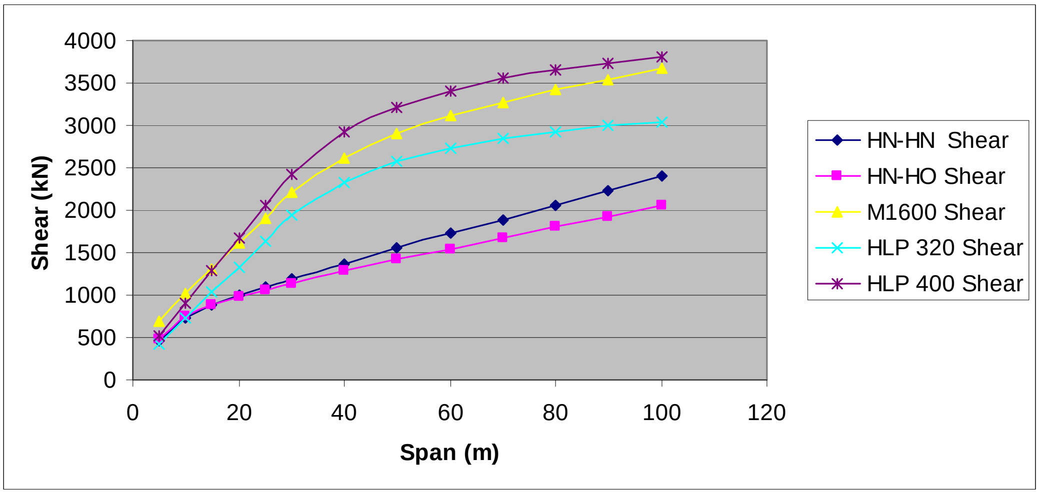


Figure 2.9 Serviceability limit state live load shear for two lanes loaded.

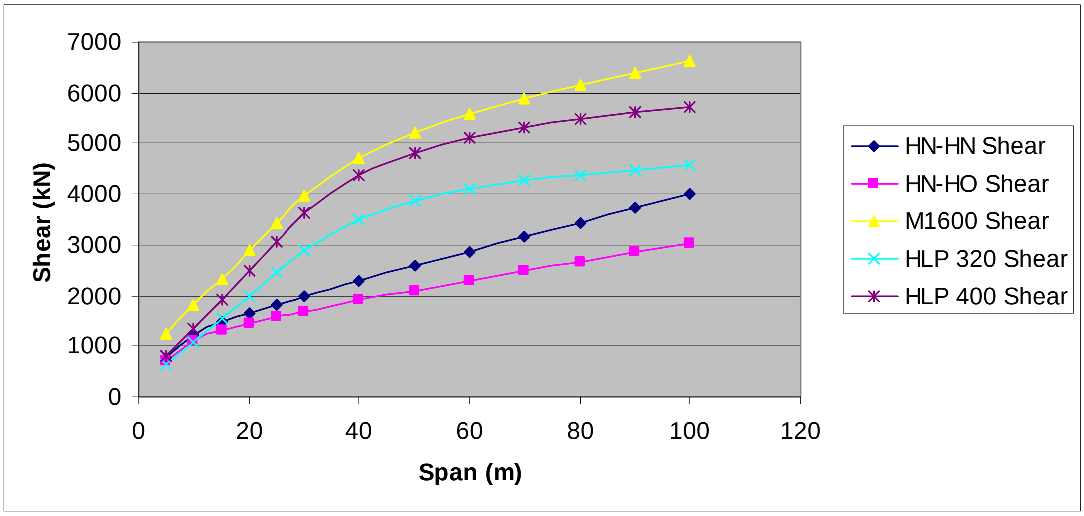


Figure 2.10 Ultimate limit state live load shear for two lanes loaded.

Reviews are recommended of the following aspects of the design criteria with a view to harmonising approaches where possible:

- dynamic load allowance factors
- centrifugal forces – harmonise the approach to level of application of the load. In other respects the AS 5100.2 and *Bridge manual* specifications are essentially similar
- braking forces – the current approaches of AS 5100.2 and the *Bridge manual* are sufficiently close and adoption of the AS 5100.2 approach is not likely to have a significant impact on design
- deflection – consideration of the adaptation of the AS 5100.2 deflection criteria to the *Bridge manual* design loadings and to recognise cambering as an appropriate approach for countering deflections under permanent loads
- distribution of traffic loads through fill – the AS 5100.2 approach appears generally satisfactory, but would require adaptation to refer to the New Zealand design traffic loads. The appropriateness of neglecting traffic loads on single spans when the depth exceeds 2.5 m should be reviewed as the span length is considered to be a relevant factor.

Development of a design fatigue load spectrum applicable to New Zealand conditions is necessary whether or not AS 5100.2 is adopted.

In the event that AS 5100.2 is adopted for use in New Zealand, it is recommended that supplementary documentation be prepared to incorporate appropriate design traffic live loading criteria. Where practical, these criteria should be harmonised in their approach with AS 5100.2.

2.7 Pedestrian and footpath load

2.7.1 Outline of coverage

Section 7 of AS 5100.2 specifies:

- the design loading for pedestrian walkways and cyclepaths on pedestrian and cycle path bridges and on walkways on road bridges

- the design loading for service walkways and platforms
- the ULS and SLS load factors to be applied to these loadings.

2.7.2 Variation of requirements from the *Bridge manual*

For walkways on road bridges, AS 5100.2 specifies a design live load of 5 kPa for loaded areas of up to 10 m^2, reducing linearly to 2 kPa for areas greater than or equal to 100 m^2. (This linear reduction is represented by the expression: w = 5⅓ – A/30.) For pedestrian bridges and walkways independent of road or rail bridge superstructures, the design load of 5 kPa applies up to a loaded area of 85 m^2 before reducing linearly to 4 kPa at 100 m^2. In each case, the loaded area is related to the structural element under consideration.

Where a vehicle could use a walkway, the walkway is to be designed to carry a concentrated load of 20 kN, without dynamic load allowance.

For service walkways and platforms, the design loading is to be taken as 2.2 kN distributed over any 0.6 m length of the walkway or platform. Service live load on access walkways not intended for public access need not be considered as acting simultaneously with traffic live load.

Load factors to be applied to the AS 5100.2 pedestrian and service live loads are given in table 2.8.

Table 2.8 Load factors for design pedestrian and service live loads.

Load	Limit state	
	Ultimate	**Serviceability**
Pedestrian loads	1.8	1.0
Service live loads	2.0	1.0

By comparison, the *Bridge manual* requires walkways at the same level as the road carriageway to be designed for highway traffic loads. Walkways raised above the carriageway and behind a kerb are to be designed for:

- 5 kPa when not considered in the same load case as traffic loading
- when traffic loads are considered in the same load case, between 1.5 kPa and 4.0 kPa based on the formula 5.0 – S/30, where S, the loaded length in metres, is the length of footpath that results in the worst effect on the member being considered
- an HN wheel load positioned with the wheel outer edge at the outer edge of the slab, treated as an overload case.

Walkways not accessible to traffic are to be designed for the first two loads above, but not the HN wheel overload.

A footbridge or cycle track bridge without traffic is to be designed for a UDL of between 2.0 kPa and 5 kPa as given by the expression 6.2 – S/25, where S is as defined above.

The *Bridge manual* does not present criteria for service access loads.

The load factor applying to the *Bridge manual* design pedestrian walkway loads for the ULS is 1.755.

2.7.3 Suitability and actions required to enable adoption

As footpaths generally exceed 1.0 m in width, the AS 5100.2 footpath UDL loading will generally reduce more rapidly in relation to the length considered than that specified by the *Bridge manual*. Which load specification is more appropriate is not clear and a more detailed review is required to ascertain this.

The AS 5100.2 specified loading for accidental loading of the footpath by a vehicle, at ⅓ that specified by the *Bridge manual*, is considered to be too light and not suitable for adoption.

This review supports the approach of specifying a service access loading, but the AS 5100.2 service access loading is potentially light, equating to approximately only two to three people. This number of people could be increased and allowance also made for equipment and materials. Different access facilities would be provided to serve different functions. A more appropriate approach may be to require access facilities to bear signage stating their capacity, and for the design loading to be based on the stated capacity.

If AS 5100.2 were adopted, supplementary documentation would be required to amend the design vehicle overload and the service access load criteria. A review of the walkway UDL loading for appropriateness is also recommended.

2.8 Railway traffic

Section 8 of AS 5100.2 has not been reviewed as it is not relevant to road bridges.

2.9 Minimum lateral restraint capacity

2.9.1 Outline of coverage

Section 9 of AS 5100.2 specifies a minimum lateral restraining force capacity to be provided to each continuous section of the bridge superstructure.

2.9.2 Variation of requirements from the *Bridge manual*

AS 5100.2 specifies that a positive lateral restraint system is to be provided between the superstructure and the substructure. For continuous superstructures, lateral restraints may be omitted at some piers provided each section of the superstructure between expansion joints is adequately restrained. The restraint system for each section of the superstructure is to be capable of resisting an ultimate design horizontal force normal to the bridge centreline of 500 kN or 5% of the superstructure dead load at that support, whichever is greater.

The nearest equivalent requirements within the *Bridge manual* are the requirements for structural robustness specified in clause 2.1.8, which requires both horizontal and vertical interconnection, but does not specify force levels, and the horizontal linkage system requirements of clause 5.6.2 of the earthquake resistant design section, which does not require transverse linkage providing the strength and stability of the span is sufficient to support an outer beam should it be displaced off the pier or abutment.

2.9.3 Suitability and actions required to enable adoption

The review supports the general principles of the AS 5100.2 provisions, but some rewording of the clause is desirable to achieve clarity on the level of restraint force capacity to be provided at individual restraint points and to continuous sections of the superstructure as a whole. To specify the restraint force capacity at a support in terms of the reaction at that support does not seem entirely logical when restraint is not required to be provided at some supports. Neither is the specification of an arbitrary total force capacity logical as the length and mass of superstructure to be restrained may vary widely from structure to structure.

If AS 5100.2 were to be adopted, it is recommended that the principles embodied in section 9 of AS 5100.2 be adopted but that a more rationally based level of restraint capacity be developed.

2.10 Collision loads

2.10.1 Outline of coverage

Section 10 of AS 5100.2 specifies design collision forces and their application for the following situations:

- traffic collision with bridge supports not located behind protective barriers
- traffic collision with protection beams positioned to protect low vertical clearance bridges
- train collision with all significant structures erected above railway tracks
- loads on railway bridges arising from derailment of a train.

2.10.2 Variation of requirements from the *Bridge manual*

The AS 5100.2 and *Bridge manual* design load and method of application for traffic collision with bridge supports are essentially equivalent. (The AS 5100.2 force is double, but the load factor one-half.) AS 5100.2 requires this loading to be considered when supports are not located behind appropriate traffic barriers, which is not at all clear, whereas the *Bridge manual* is much more specific on this issue.

The protection beams have not yet been adopted in New Zealand, although there is rising concern over the frequency of over-height vehicle strikes on bridges. Consequently, the *Bridge manual* does not currently contain equivalent provisions for loads on protection beams. On the other hand, the *Bridge manual* does specify design collision loads for bridge superstructures that are of a much smaller magnitude than the forces specified by AS 5100.2 for protection beams.

The *Bridge manual* provisions for train collision were adopted from the 1992 Austroads Bridge Design Code, and so bear some similarity to the AS 5100.2 requirements. However, these have been extensively revised and extended in AS 5100.2. These now provide the option of designing the bridge with sufficient redundancy to be able to sustain loss of one or more piers without collapse under its dead load plus 20% of the live load, or of designing to resist the specified collision loads on the bridge piers. The AS 5100.2 ULS design collision loads (ie ULS load factor x force) have undergone a reduction to 75% of the *Bridge manual* loads, but the clearance width from the railway centreline within which this loading is required to be considered has been increased from 5.5 m to 10 m. For the clearance from 10 m out to 20 m, AS 5100.2 has a requirement for a collision load of 1500 kN to be considered in any horizontal direction. Also, but not concurrent with the loads above, any part of a structure within 10 m horizontally or 5 m vertically is to be designed for a 500 kN ULS collision load, reducing above 5 m to 0 at 10 m height.

Possible ship impact on bridge piers is also required to be considered by the *Bridge manual*, but this load is not covered in AS 5100.2.

2.10.3 Suitability and actions required to enable adoption

The AS 5100.2 requirements for collision load from traffic require clarification of the conditions under which they are to be applied. This needs to include the extent of set-back from the carriageway edge if unprotected, and the standard of barrier protection if shielded by barriers.

The requirements for train collision related to provision of an alternative load path should also clarify when more than one pier is to be considered removed.

The collision load due to traffic compared with that due to a train appears to be disproportionate. The design loads are high and have the appearance of being based on arbitrary judgement. Some of the structural forms in current use for railway overpasses, such as Armco arch culverts and precast double hollow core unit decks supported on mechanically reinforced earth walls, are unlikely to meet the AS 5100.2 requirements for train collision loads.

It is recommended that a detailed review of requirements for train collision loading be undertaken. A risk-based approach and a focus on designing for robustness may be more appropriate than designing for excessively high or arbitrary loads that may not be able to be accommodated economically. Trains are, after all, guided vehicles, the derailment of which is relatively rare and their collision with structures even more rare.

If AS 5100.2 were to be adopted supplementary documentation should be prepared to:

- clarify the circumstances when design for traffic collision loads on supports is required
- incorporate a design traffic collision loading for bridge superstructures
- clarify, for train collisions and the alternative load path approach, when more than one pier is to be considered to be removed
- present alternative requirements for train collision based on the detailed review recommended above
- incorporate requirements for withstanding possible ship impact.

2.11 Kerb and barrier design loads and other requirements for road traffic barriers

2.11.1 Outline of coverage

Section 11 of AS 5100.2 specifies:

- the design lateral load for kerbs
- requirements for the development of a prototype barrier or minor modifications to a barrier system
- the design loads for low and regular performance barriers*
- the required effective and minimum actual heights for low and regular performance barriers*
- criteria for the design of barrier anchorages (interpreted as the connection of the barrier to the bridge deck)
- requirements for barrier continuity
- criteria for the design of deck slab cantilevers to resist barrier loads

- requirements for expansion joints and end parapets
- design loadings for pedestrian barriers.

*Note: Similar requirements for higher capacity barriers are covered in appendix A of AS 5100.2

2.11.2 Variation of requirements from the *Bridge manual*

2.11.2.1 Traffic barrier acceptance criteria and design loads

For kerbs, AS 5100.2 specifies only a lateral ULS design force of 15 kN/m whereas the *Bridge manual* requires kerbs to be designed for concurrent lateral ULS loading of 16.5 kN/m plus a vertical HN wheel load.

AS 5100.2 sets out requirements for prototype barrier systems and modified performance validated barrier systems. The *Bridge manual* on the other hand sets out barrier acceptance criteria requiring that barriers comply with one of the following criteria:

- The barrier has undergone satisfactory crash testing to the appropriate test level in accordance with *NCHRP Report 350* (1993) with a maximum deflection not greater than 600 mm.
- The barrier system is based on similar crash-tested barriers used elsewhere with a maximum deflection not greater than 600 mm, subject to Transit approval.
- The barrier system is one that is deemed to comply by Transit.

The *Bridge manual* also provides a table of approved non-proprietary solutions.

AS 5100.2 specifies design loads for low and regular performance barriers. The loads for regular performance barriers correspond to those specified by the *Bridge manual* for performance level 4 barriers. As noted in section 1.10, the low performance level barriers specified by AS 5100.2 are below the minimum performance standard specified by the *Bridge manual* which adopts performance level 3 corresponding to NCHRP TL3 as its lower bound barrier performance level. Otherwise the barrier design forces and methods of application, and barrier effective height requirements are essentially the same. The *Bridge manual*, clause B6.1, fails to state that the design loads tabulated in table B3 are ULS loads for which the appropriate load factor is 1.0.

2.11.2.2 Traffic barrier failure hierarchy

AS 5100.2 establishes a hierarchy of failure of the barrier system through the application of varying ULS load factors, applying a load factor of 1.0 to the design of the barrier, a load factor of 1.05 to the design of the barrier anchorages, and a load factor of 1.1 to the design of deck cantilevers for the barrier forces. The *Bridge manual*, on the other hand, requires failure to be confined to the barrier system and/or its fixings with the deck slab to remain undamaged. A higher load factor is applied to the design of the deck slab to ensure this outcome.

2.11.2.3 Traffic barrier continuity and expansion joints

AS 5100.2 presents requirements for the strengths and detailing of rail splices, and requires rigid parapets at expansion joints to stand alone without shear key interconnection. Where gaps greater than 25 mm could develop between adjacent panels, bridging plates are to be provided. There are no comparable requirements in the *Bridge manual*.

2.11.2.4 Pedestrian barriers

Pedestrian barrier design forces differ between AS 5100.2 and the *Bridge manual*. AS 5100.2 requires the following:

- longitudinal members to be designed for a simultaneous transverse and vertical load of 0.75 kN/m, or the appropriate wind load, whichever is most adverse
- where an authority requires barriers to restrain crowds or people under panic conditions, this loading is increased to 3.0 kN/m transversely and vertically
- static deflections due to the above loadings to not exceed:
    - for longitudinal members: L/800
    - for posts; h/300
- load factors for these loadings are to be taken as 1.8 for the ULS and 1.0 for the SLS.

The *Bridge manual* separates the barrier into its elements and requires the following:

- the top rail to be designed to resist a horizontal and vertical service load of 1.75 kN/m, non-concurrently
- other members to resist a horizontal service load of 1.5 kN/m^2 applied to the gross area and a point load of 0.5 kN applied at any point
- the load factor to be taken for the ULS is 1.7.

2.11.2.5 Combination traffic – pedestrian barriers

The *Bridge manual* presents requirements for combined pedestrian/traffic barriers mounted on a kerb with a 500 mm wide strip, or on a footpath with a kerb. For these:

- the traffic barrier portion is to meet the requirements for the appropriate barrier performance level
- the handrail top rail portion is to resist loads of 4.4 kN/m horizontally and 1.75 kN/m vertically, and the loadings on other handrail components are as set out above for hand rails
- deflection of the barrier is to be limited to prevent the impact side wheel having less than 100 mm of contact width with the bridge deck.

2.11.3 Suitability and actions required to enable adoption

The AS 5100.2 requirements alone are insufficient to adequately reflect Transit's requirements. If AS 5100.2 were to be adopted, detailed review of some aspects and supplementary documentation would be required in the following areas:

- Transit's traffic barrier acceptance criteria
- barrier design loads for performance level 3 traffic barriers
- the traffic barrier failure hierarchy. AS 5100.2's load factors are unlikely to be sufficient to ensure that damage to the bridge deck is avoided because of strain hardening in the yielding steel of the barrier
- expansion joints and end parapets. The justification for prohibiting shear keying between the abutting ends of adjacent parapets at expansion joints is not clear and in fact measures that limit the differential transverse displacement of one section of parapet relative to the next are considered to be beneficial, reducing the likelihood of the colliding vehicle being snagged

- the design loads for pedestrian barriers (in view of the significant differences in the AS 5100.2 and *Bridge manual* design loadings). The AS 5100.2 design loading is felt to be low, but inclusion of requirements for crowd loading is supported. In the rural environment, consideration may also need to be given to the containment of stock being herded.
- the design loadings for handrails mounted on top of traffic barriers.

2.12 Dynamic behaviour

2.12.1 Outline of coverage

Section 12 of AS 5100.2 encompasses the vibrational behaviour of:

- road bridges with pedestrian walkways
- road bridges without walkways
- railway bridges
- pedestrian bridges

2.12.2 Variation of requirements from the *Bridge manual*

2.12.2.1 Road bridges

For road bridges, AS 5100.2 specifies deflection limits under static loading (a proportion of the M1600 loading without UDL), which if exceeded requires a dynamic analysis of the bridge's vibrational behaviour. It fails, however, to define acceptance criteria in the event of a dynamic analysis being required.

The *Bridge manual*, by comparison, requires the maximum vertical velocity during a cycle of vibration under its specified design load (two 120 kN axles of one HN load element) to be limited to no greater than 0.055 m/sec. However, it fails to adequately define how the loading is to be applied in order to derive the maximum velocity associated with vibration of the bridge.

2.12.2.2 Pedestrian bridges

For pedestrian bridges, AS 5100.2 requires bridges with resonant frequencies of vertical response within the range of 1.5 Hz to 3.5 Hz to be investigated for vibrational response under a 700 kN load traversing the bridge at an average walking speed of 1.75 to 2.5 footfalls per second. Under this action the maximum dynamic deflection is to be within defined limits which vary with the frequency of vibration. The *Bridge manual* adopts the BS 5400 approach for design of pedestrian bridges for vibration. This requires bridges with a fundamental frequency (f_0) in the vertical direction of less than 5 Hz to be assessed and the maximum vertical acceleration to be limited to less than $0.5\sqrt{f_0}$ m/sec. It provides a simplified method for symmetrical, constant cross-section, single span or two or three span continuous bridges, and a more rigorous method for more complex bridge structures.

2.12.3 Suitability and actions required to enable adoption

Adoption of the AS 5100.2 procedures appears to be attractive, but a review would be required to ensure that they deliver appropriate outcomes. Adaptation of the approach for road bridges to the New Zealand design traffic loading may also be necessary.

For road bridges, AS 5100.2 offers an attractively simple initial approach; however, it is based on the AS 5100.2 design traffic live loading. If the AS 5100.2 design traffic live loading is not adopted, then design loadings and acceptance criteria based on the adopted design traffic live loading would need to be developed to adopt the AS 5100 method. For situations where dynamic analysis is required, acceptance criteria would need to be developed for the AS 5100.2 approach to be used.

For pedestrian bridges, the AS 5100.2 load of 700 N appears to be unrealistically high as the 'dynamic excitation' load, and the speed of travel of the person across the bridge is not well defined. By comparison, the BS 5400 part 2 loading adopted by the *Bridge manual*, applies a sinusoidally varying load with a peak magnitude of 180 N, which appears more reasonable, but the reason for the velocity of travel of the load varying with the fundamental frequency of vibration is not clear. However, these loadings taken together with their acceptance criteria are simulations designed to determine thresholds between acceptable and unacceptable dynamic response, and so the loadings cannot be considered in isolation from acceptance criteria. In view of what appears to be a very high dynamic excitation load being applied by AS 5100.2 for pedestrian bridges, a review of the AS 5100.2 criteria is recommended to ensure that it is producing appropriate outcomes.

To adopt the AS 5100.2 approach, supplementary documentation would be required to clarify the vibrational behaviour requirements. The coverage of that documentation would have to include as a minimum:

- specification of the design loadings for road bridges
- specification of the acceptance criteria for road bridges requiring dynamic analysis
- clarification of the speed of travel of the design load for pedestrian bridges.

If the current *Bridge manual* criteria for road bridges is retained, the manner of application of the loading and derivation of the vertical velocity would need to be clarified.

2.13 Earth pressure

2.13.1 Outline of coverage

Section 13 of AS 5100.2 refers to AS 5100.3 for load effects from earth pressures on soil retaining structures, which is covered in the review of AS 5100.3. In addition it also covers:

- surcharge loads from traffic loads
- surcharge loads from railway loads.

2.13.2 Variation of requirements from the *Bridge manual*

AS 5100.2 simulates highway live loading within a distance from a wall equal to the effective height of the wall as the effect of an additional soil surcharge which diminishes over the height of the wall as shown in figure 2.11. The effect of foundations placed on or in the fill within a distance from the wall equal to the effective height is also to be taken into account. In comparison, the *Bridge manual* allows live load effects to be simulated by the effect of 0.6 m of soil surcharge, with no reduction in the effect as the depth increases.

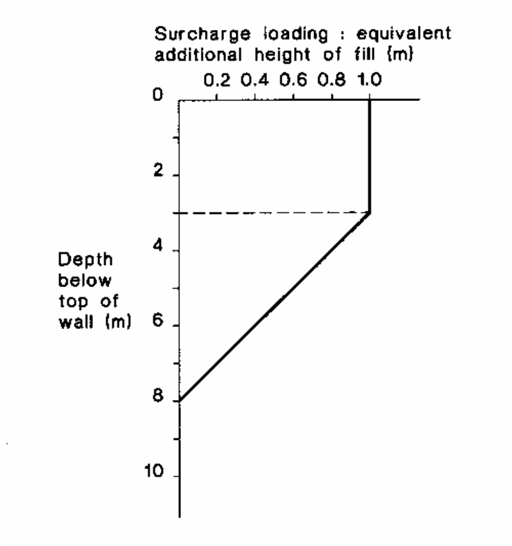


Figure 2.11 Equivalent load due to live load surcharge.

AS 5100.2 provides a method for the simulation of railway loads within a distance from the wall equal to the effective wall height as surcharge loads. No equivalent provision is made by the *Bridge manual*.

2.13.3 Suitability and actions required to enable adoption

The AS 5100.2 surcharge load is designed to be an appropriate simulation of the AS 5100.2 traffic design load effects on retaining walls. If the AS 5100.2 design traffic loads are not adopted for use in New Zealand, and the HN-HO loading is retained, then the *Bridge manual* simulation of traffic live loading by a 0.6 m fill surcharge should also be retained. This would require supplementary documentation should AS 5100.2 be adopted.

AS 5100.2 is considered to provide an appropriate method for simulation of the effects of train loading on earth retaining structures.

2.14 Earthquake forces

2.14.1 Outline of coverage

Section 14 of AS 5100.2 covers the following:

- general requirements – this includes reference to AS 1170.4 for aspects of the calculation of common earthquake effects
- earthquake effects to be considered at the ULS for members strengths, overall stability of the structure and its members, and horizontal movements
- bridge categorisation for earthquake resistant design
- the methods of analysis and detailing to be applied to bridges of different categorisation
- requirements for static analysis
- requirements for dynamic analysis
- details of structural requirements for earthquake effects.

2.14.2 Variation of requirements from the *Bridge manual*

AS 5100.2 devotes about six pages to the coverage of earthquake resistant design, a topic to which a 40-page section is devoted in the *Bridge manual*. The hazard spectra for AS 5100.2 are drawn from AS 1170.4, while the *Bridge manual* adopts the hazard spectra of NZS 1170.5.

Earthquake resistance is usually a dominant aspect of structural design in New Zealand, whereas it is a much less dominant aspect of design in Australia. This is reflected in the depth of coverage given to the topic by each of the two standards. It is impractical within this review of AS 5100.2 to compare in detail all the aspects of seismic resistant design and record the differences. It is sufficient to note that the *Bridge manual* coverage is both far more comprehensive in its analysis and design requirements and incorporates seismic hazard spectra appropriate to New Zealand which AS 5100.2 does not.

This aspect of the *Bridge manual* is currently in the process of undergoing revision for compatibility with the principles of AS/NZS 1170.0 and to incorporate the design loading and aspects of the analysis requirements of NZS 1170.5.

2.14.3 Suitability and action required to enable adoption

The AS 5100.2 requirements do not incorporate seismic hazard spectra for New Zealand or provide the necessary depth of treatment for such a dominant aspect of structural design in New Zealand. If AS 5100.2 were adopted, extensive supplementary documentation would be required to largely replace this section and incorporate seismic resistant design criteria appropriate to New Zealand conditions. These could incorporate aspects of the AS 5100.2 design requirements as appropriate.

It has been suggested that AS 5100.2 could be adopted for the low seismicity areas of New Zealand. In the same way as AS 1170.4 was not adopted by the Standards New Zealand committee for earthquake structural design actions for low seismicity areas, it is the view of the authors of this review that one consistent approach for all New Zealand should be adopted based on the philosophy incorporated in NZS 1170.5 to ensure acceptability of designs for gaining building consent under the New Zealand Building Act.

2.15 Forces resulting from water flow

2.15.1 Outline of coverage

Coverage is given in section 15 of AS 5100.2 to the following:

- the range of water actions to be to be considered
- the nature of the limit states and their assessment
- forces on piers due to water flow (both drag and angle of attack actions)
- forces on the superstructure due to water flow (both drag and lift actions)
- forces due to debris rafts
- forces due to log impact
- treatment of the effects of buoyancy and lift.

2.15.2 Variation of requirements from the *Bridge manual*

2.15.2.1 Actions to be considered

AS 5100.2 specifically names the various forms of water flow actions that are required to be considered, including tidal and wave action on bridges across estuaries and the open sea, which are not mentioned in the *Bridge manual*.

2.15.2.2 Limit states

For the ULS, AS 5100.2 requires bridges to withstand flood events up to a 2000-year return period without collapse. The *Bridge manual*, by comparison, assigns the maximum ULS return period event on the basis of bridge importance with the return ranging up to 5000 years for the bridges of highest importance category, and 2500 years for most state highway bridges. Both codes draw attention to the critical design condition possibly occurring at a return period less than the maximum ULS return period, but only AS 5100.2 scales the ULS load factor, γ_{WF}, according to the return period (ARI) of the critical condition, as follows:

$$\gamma_{WF} = 2 - 0.5 \log(ARI/20)$$

This adds to the complexity of deriving the critical condition.

AS 5100.2 defines the SLS as being the capability of the road and bridge system to remain open or to sustain an overtopping flood without damage, and sets the SLS design flood as a 20-year return period event. The *Bridge manual*, on the other hand requires bridges to withstand a 25-year return period flood event without damage and to remain trafficable in SLS I return period events which vary according to the importance category of a bridge. For most state highway bridges the SLS I return period corresponds to 100 years.

AS 5100.2 fails to define a flow to be treated as normal water flow, to be considered to act in combination with other design actions. The *Bridge manual* sets this as the one-year annual recurrence interval flow.

2.15.2.3 Forces on piers due to water flow

Design forces on piers are derived in a similar manner by both AS 5100.2 and the *Bridge manual*. AS 5100.2 refers to 'lift forces on piers', which is confusing terminology. The forces referred to are forces on wall or slab type piers, perpendicular to their plane, arising from their orientation not being parallel to the direction of the water flow. For piers inclined to the flow at angles less than 30^o, the *Bridge manual* varies the design force coefficient according to the angle of attack, whereas AS 5100.2 adopts the same force coefficient for the whole range of angle of attack from 0^o to 30^o.

An error exists in the *Bridge manual* derivation of forces acting on face areas normal to the flow, in that the angle of attack factor applied in deriving K should be taken as 1.0.

2.15.2.4 Forces on superstructures due to water flow

AS 5100.2 derives the drag force of the superstructure as a function of its relative submergence and its proximity to the river bed, and the 'lift' or 'angle of attack' factor also a function of the relative submergence, both with further adjustments to be applied for bridge superelevation. The *Bridge manual*, more simplistically, adopts a single drag coefficient for all situations (which requires correction as noted above) and an angle of attack factor derived on the same basis as for piers. For bridges with proximity ratios at the lower end of the range, AS 5100.2 gives drag forces on superstructures up to 50% higher than the *Bridge manual*.

AS 5100.2 also provides a method for calculation of the rotational moment about the bridge longitudinal axis imposed on the superstructure by the water flow. This is not covered in the *Bridge manual*.

2.15.2.5 Forces due to debris

AS 5100.2 leaves somewhat open the depth to be adopted for the debris raft, suggesting a value in the range of 1.2 m to 3.0 m in the absence of an accurate estimate. For debris rafts acting on piers, AS 5100.2 adopts a debris raft length of half the sum of the lengths of the adjacent spans, but not greater than 20 m. Where the flood level is above 600 mm below the soffit of the superstructure, a debris raft is also assumed to act on the superstructure over its projected length. Drag forces for debris rafts on piers and the superstructure are derived as functions of the water velocity and water depth, and lift on the superstructure is derived using a constant coefficient.

The *Bridge manual*, by comparison, defines the debris raft acting on a pier as a triangular shape with a length equal to half the sum of the lengths of the adjacent spans but not greater than 15 m, and a depth of half the water depth but not greater than 3.0 m. It does not cover debris rafts acting on the bridge superstructure.

2.15.2.6 Forces due to log impact

AS 5100.2 specifies a log impact loading, corresponding to a 2-tonne log being stopped within a defined distance which varies according to the form of pier construction. This is considered non-concurrent with the water flow force acting on a debris raft. The *Bridge manual* has no similar requirement.

2.15.2.7 Buoyancy and lift

AS 5100.2 requires positive tie-down of the superstructure to be provided for a force equal to 1.5 x ULS lift force + buoyancy – Y_gDL, where Y_g is the lower value applied as the dead load ULS load factor where dead load increases safety. Requirements are also specified for considering the effects of lift and buoyancy on the substructure, for bleed holes to be provided to allow the escape of air trapped beneath the superstructure, and for the drainage of internal cells of the superstructure.

Other than the requirement for all parts of the structure to be interconnected to provide structural robustness, the *Bridge manual* does not present specific requirements to resist lift and buoyancy actions.

2.15.3 Suitability and actions required to enable adoption

The AS 5100.2 provisions for forces resulting from water flow are generally more comprehensive and suitable than those presented by the *Bridge manual*, and so are recommended for adoption, but would benefit from clarification or improvement of the following areas:

- The term 'lift forces' in respect to piers is inappropriate and should be changed to 'angle of attack' or similar wording.
- For angles of attack on piers < 30^{o}, presentation of a range of angle of attack (lift) factors, C_L, for varying angles of attack would be beneficial.

- A clearer, more definitive description of the size and shape of the design debris raft is desirable. Possibly also, details are required of how the debris raft load is to be shared between the pier and the superstructure when it acts on both, as the load is derived differently depending on which part of the structure it acts on.

The design return periods for the ultimate and serviceability limit state adopted by the *Bridge manual* align with the philosophy of AS/NZS 1170, which is expected to be adopted by the Department of Building and Housing as an approved document under the NZBC. Alignment with AS/NZS 1170 is considered to be desirable to aid gaining building consents for bridge projects, and therefore it is recommended that the *Bridge manual* design return periods are retained.

What load factor should be applied for the ULS load case will require review in conjunction with a review of load factors for all ULS load combinations, should AS 5100.2 be adopted. Varying the load factor with return period is not favoured, because of the complexity it would add to the determination of the critical condition and because the basis for doing so is not clear.

Should AS 5100.2 be adopted, supplementary documentation is recommended to incorporate the clarifications and improvements suggested above and to retain the *Bridge manual* specification of ULS and SLS design return periods.

2.16 Wind loads

2.16.1 Outline of coverage

Coverage is given in section 16 of AS 5100.2 to the following:

- the nature of structures to which this section applies
- derivation of the design wind speed and the return periods appropriate to the ULS and SLS
- derivation of the design transverse wind load
- derivation of the design longitudinal wind load
- derivation of the design vertical wind load
- wind on railway live load.

2.16.2 Variation of requirements from the *Bridge manual*

The design return periods adopted by AS 5100.2 and the *Bridge manual* differ for wind load in the same manner as the return periods for forces due to water flow.

Both codes draw on AS/NZS 1170 as the basis for deriving the design wind speed.

AS 5100.2 adopts a design return period of 2000 years for the ULS, and for the SLS wind considered in combination with permanent effects only, a 20-year return period. For wind acting in conjunction with live load the wind speed is taken as 35 m/sec, but the effect of wind on road traffic need not be considered.

The *Bridge manual*, for the ULS, adopts design return periods varying according to the importance of the structure, ranging up to 5000 years for the most important structures, but 2500 for most state highway bridges. For the SLS, the design return period is taken as 25 years. For wind load acting in conjunction with live load, the design wind speed is to be taken as the lesser of 37 m/sec or the design wind speed for the limit state being considered, and the effect of wind acting on the live load is taken into account in deriving the wind loading. The *Bridge manual* adopts the BS 5400 Part 2 approach, which requires consideration of wind acting on adverse and relieving areas, and reduces the wind speed for wind acting on relieving areas.

The BS 5400 Part 2 and AS 5100.2 approaches have a lot of similarity in their derivation of drag and lift coefficients and loaded areas, but the BS 5400 approach is generally a little more refined.

For footbridges with spans exceeding 30 m, for which dynamic effects may be critical, the *Bridge manual* adopts the principles given in 'Design rules for aerodynamic effects on bridges', *Design manual for roads and bridges, Part 3 BD 49/01*. (UK Highways Agency 2001).

2.16.3 Suitability and actions required to enable adoption

The design return periods for the ultimate and serviceability limit adopted by the *Bridge manual* align with the philosophy of AS/NZS 1170, which is expected to be adopted by the Department of Building and Housing as an approved document under the NZBC. Alignment with AS/NZS 1170 is considered desirable for building consent purposes, and therefore it is recommended that the *Bridge manual* design return periods are retained.

With long linear structures the gust effects of wind will vary along the length of the structure and thus it is appropriate to consider the adverse and relieving areas given in BS 5400 Part 2. Aerodynamic effects may also be critical for longer span footbridges, requiring more refined methods than those provided by AS 5100.2.

If AS 5100.2 were adopted, the *Bridge manual* requirements for wind load should be retained since they are more comprehensive than those presented by AS 5100.2.

2.17 Thermal effects

2.17.1 Outline of coverage

Coverage is given in section 17 of AS 5100.2 to the following:

- the effects of variation in bridge temperature
- the temperature ranges to be adopted for different forms of bridge construction
- differential temperature effects and the temperature gradients to be adopted for different superstructure forms
- the consideration of thermal effects at the ULS and SLS.

2.17.2 Variation of requirements from the *Bridge manual*

2.17.2.1 Overall temperature change

AS 5100.2 presents maximum and minimum shade air temperatures for different regions of Australia and corresponding average bridge temperatures to various maximum and minimum air temperatures. For superstructures of concrete deck on steel beams, and steel deck on steel beams, adjustments to the bridge average maximum and minimum temperatures are also provided. For concrete bridges these temperatures provide a maximum range of 46^{o}, but give a more typical range of about 40^{o}. For a concrete deck on steel beams the minimum temperature is reduced by 5° and the maximum temperature increased by 10°, giving a typical temperature range of about 55°.

By comparison the *Bridge manual* simply requires concrete bridges to be designed for a temperature range from mean temperature of ±20°, and steel bridges for a temperature range of ±25°.

In the consideration of restraint forces mobilised in the structure, the *Bridge manual* states that cracked section properties are to be assumed for deriving the rigidity of concrete piers, whereas AS 5100.2 has no similar requirement.

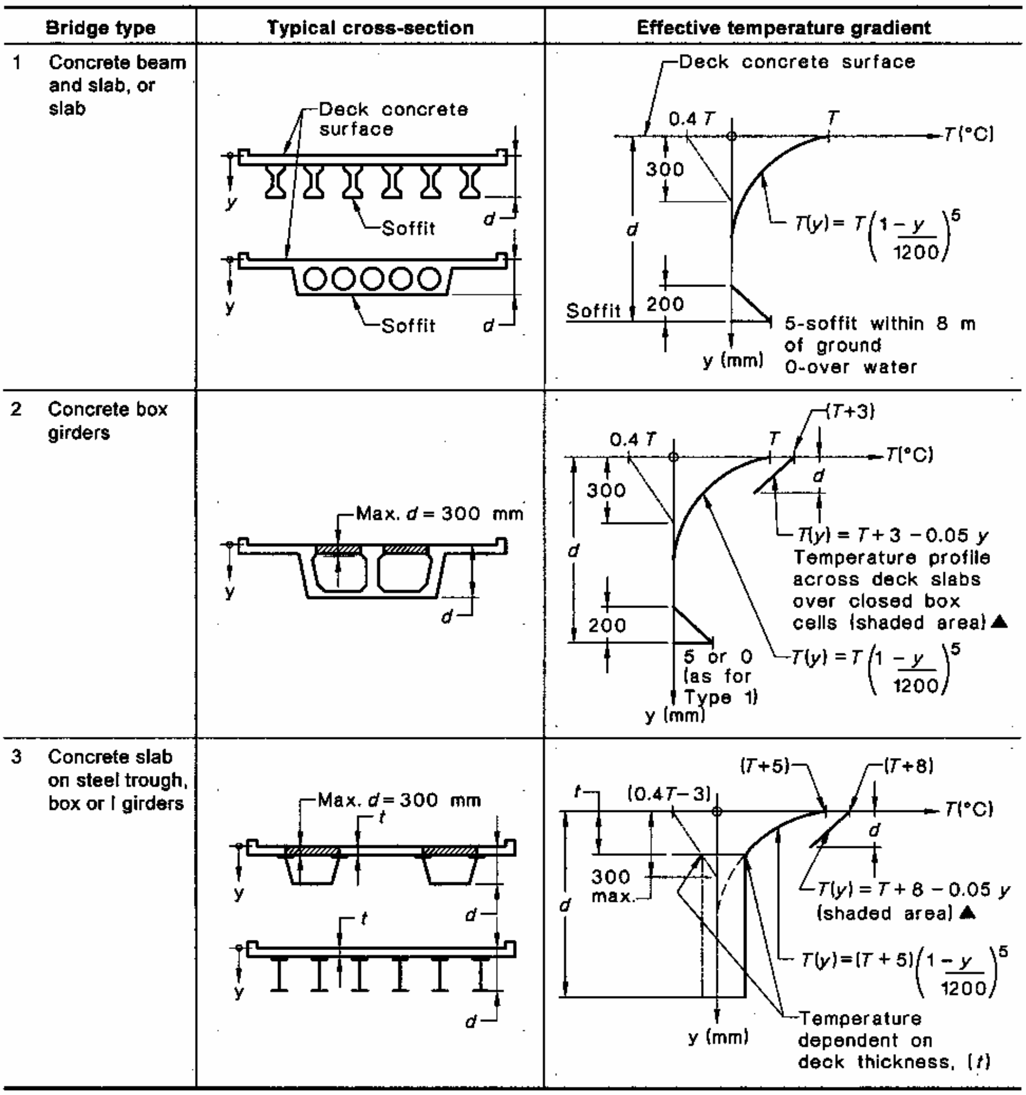
2.17.2.2 Differential temperature

AS 5100.2 requires differential temperature to be considered for both positive temperature differential conditions, where solar radiation has caused a gain in the top surface temperature, and for negative temperature differential conditions, where re-radiation of heat from the section results in a low top surface temperature. The *Bridge manual* does not require the consideration of negative temperature differential.

AS 5100.2 presents three different differential temperature gradient curves, appropriate to the different superstructure forms of:

- concrete deck on concrete beams, or slab
- concrete box girders
- concrete slab on steel trough, box or I girders.

These are shown in figure 2.12.



Key

———	Positive differential temperature gradients
– – – –	Negative differential temperature gradients

Regional values for T

Region	T	Regional category
1	20°C	Continental-inland of Great Dividing Range or further than 200 km from coast (typical Canberra, Alice Springs)
2	18°C	Coastal temperature—No further than 200 km from coast (typical Perth, Adelaide, Melbourne, Sydney)
3	14°C	Coastal sub-tropical, monsoonal (typical Brisbane, Darwin)

NOTE: The temperature gradient given for deck slabs forming closed box cells should only apply for slab thicknesses, including any internal fillets, of *d* less than 300 mm. Therefore, any deck slab, or part thereof, over a box cell with a thickness greater than 300 mm, should be subject to the general effective vertical temperature gradient shown.

Figure 2.12 AS 5100.2 design effective vertical temperature gradients.

The deck surface reference temperature for the temperature gradient curve is varied according to the region of Australia. The curves are of a similar form to that adopted by the *Bridge manual* single curve, shown in figure 2.13, but in general the reference temperatures adopted by AS 5100.2 are lower than those adopted by the *Bridge manual*.

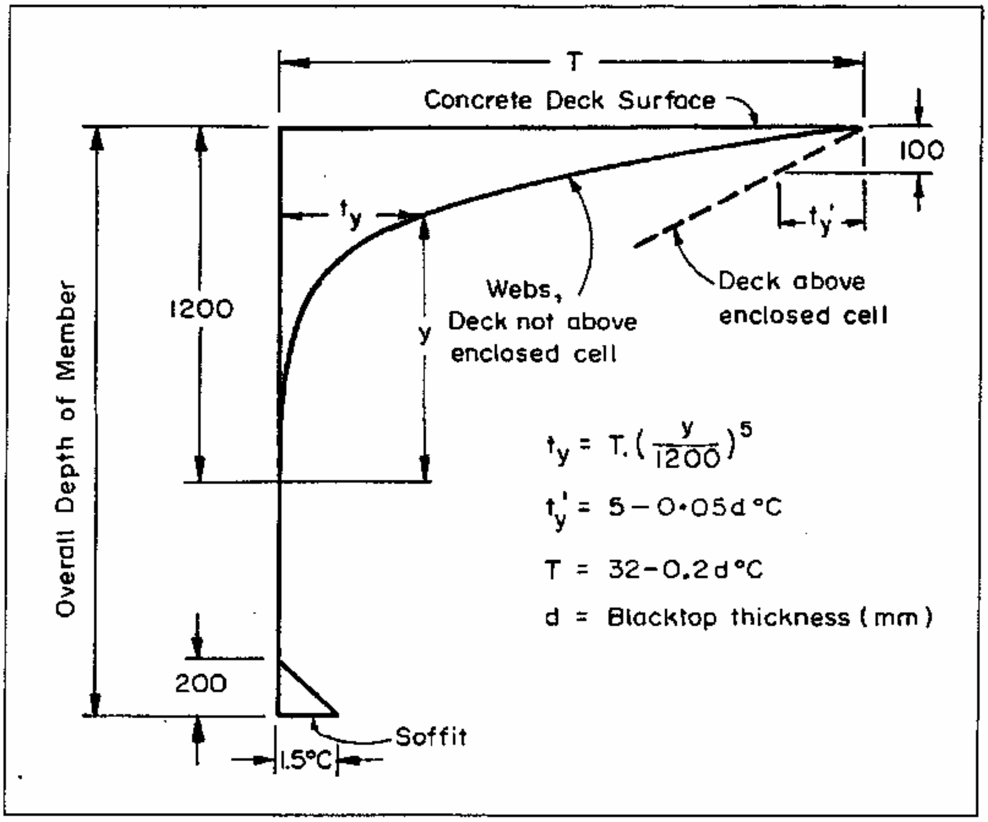


Figure 2.13 ***Bridge manual*** **vertical temperature gradient.**

Again, the *Bridge manual* requires cracked sections to be used for the analysis of reinforced concrete members subjected to differential temperature effects.

AS 5100.2 draws attention to the possible need to consider differential temperature effects in the transverse direction in wide bridges.

2.17.2.3 Limit states

For the ULS, AS 5100.2 requires thermal effects as determined by the relevant materials section to be considered, and assigns a load factor of 1.25. The steel section requires all effects to be considered, while the concrete section does not appear to present any requirements beyond the combination of factored loads as set out in AS 5100.2.

2.17.3 Suitability and actions required to enable adoption

The AS 5100.2 treatment of overall temperature effects is geared to Australia and would need supplementary data to enable application in New Zealand. However, the temperature ranges derived from the Australian data tend to indicate that the *Bridge manual* approach produces a similar outcome while the requirements are much more simply expressed.

For differential temperature, a detailed study is needed to compare the results from applying the differential temperature gradient curves from both AS 5100.2 and the *Bridge manual*. Should the AS 5100.2 curves be adopted, they would need calibration to derive an appropriate reference temperature for New Zealand conditions.

If the *Bridge manual* requirements were retained, they should be revised to require consideration of both positive and negative differential temperature gradient.

If AS 5100.2 were adopted, supplementary documentation would be required to incorporate temperature ranges for overall temperature change effects, and appropriate reference temperatures for differential temperature for different bridge types appropriate to New Zealand conditions. The use of cracked sections to model member rigidity should also be incorporated.

2.18 Shrinkage, creep and prestress effects

2.18.1 Outline of coverage

Section 18 of AS 5100.2 covers:

- shrinkage and creep effects
- prestress effects.

2.18.2 Variation of requirements from the *Bridge manual*

AS 5100.2 requires consideration of shrinkage and creep effects taking into account the characteristics of different concrete types and age. The design effects are to be calculated based on the nominal dead loads on the structure, whereas it is the permanent loads on the structure that should be considered. Loads factors for shrinkage and creep of 1.2 for the ULS and 1.0 SLS are specified.

AS 5100.2 requires the secondary effects of prestress induced in restrained components and indeterminate structures, and the case of dead load plus prestress at transfer to be considered. Load factors of 1.0 are specified for both the ULS and SLS.

The *Bridge manual* specifies that cracked sections be used for determining section rigidity in modelling the structure to analyse for the effects of shrinkage, creep and prestress, and that restraint by bearings be allowed for. Also, allowance is to be made for differential shrinkage between elements in composite structures. AS 5100.2 has no similar requirements.

2.18.3 Suitability and actions required to enable adoption

While the requirements of AS 5100.2 are generally suitable for adoption, it is recommended that they are extended through supplementary documentation to incorporate the additional appropriate requirements of the *Bridge manual*.

In addition, it is recommended that a review is undertaken of the load factors adopted by AS 5100.2. The ULS load factor of 1.0 for prestress effects is considered to be too low, as there is potential variability associated with this load.

2.19 Differential movement of supports

2.19.1 Outline of coverage

Section 19 of AS 5100.2 covers:

- differential settlement arising from settlement of supports under load
- the effects of ground subsidence due to mining.

2.19.2 Variation of requirements from the *Bridge manual*

For road bridges, AS 5100.2 requires differential settlement under the permanent loads acting on the structure to be assessed and taken into account. The relief afforded by creep and soil-structure interaction should also be considered. Differential settlement is to be taken into account at the SLS, but consideration should be given as to whether differential settlement effects need to be included at the ULS. Where a structure has limited plastic capacity, differential settlement is to be included at the ULS using a load factor of 1.5. Differential settlement due to mining subsidence is to be designed for at the SLS using a load factor of 1.0, and at the ULS using a load factor of 1.5.

The *Bridge manual* requires both horizontal and vertical displacements induced on or within the structure due to the need to take ground deformation into account, and identifies additional causes of ground deformation to be considered, eg groundwater changes and soil liquefaction.

2.19.3 Suitability and actions required to enable adoption

The AS 5100.2 requirements for differential movement are generally suitable for adoption but it is recommended that differential movement should be included at the ULS.

There are divergent views on whether differential settlement needs to be included at the ULS or not. A clear statement on the need to include this action is required. Ignoring differential settlement at the ULS will lower the threshold at which inelastic behaviour due to other actions, eg earthquake, will initiate and cause damage. For this reason it should be included. AS 5100.2 is inconsistent in requiring mining subsidence to be considered, but not specifying whether differential settlement due to other causes should be considered. There is no rational reason for such a differentiation.

If AS 5100.2 were adopted supplementary documentation would have to:

- require differential settlement at the ULS
- draw attention to other causes of ground deformation
- require consideration of horizontal and rotational deformations imposed on the structure.

2.20 Forces from bearings

2.20.1 Outline of coverage

Section 20 of AS 5100.2 sets out requirements for consideration of the forces arising from the friction of sliding and rolling bearings and from the force/displacement characteristics of elastomeric bearings.

2.20.2 Variation of requirements from the *Bridge manual*

AS 5100.2 requires the determination of bearing frictional forces based on the nominal dead loads of the structure and the characteristic coefficient of friction for the bearing. For the ULS, a load factor of 1.3 is applied to bearing frictional forces. For surfaces intended to slide to accommodate movement, a coefficient of friction equal to zero is to be considered as one ULS. The effects of seizure of a bearing are also to be considered.

The *Bridge manual* does not present any specific requirements for forces from bearings.

2.20.3 Suitability and actions required to enable adoption

The AS 5100.2 requirements are generally suitable for adoption. How bearing frictional forces are to be treated at the ULS could be more clearly expressed. In effect, upper and lower bounds are to be considered through applying a load factor of 1.3 or taking the friction coefficient as zero.

The treatment of the forces from the distortion of elastomeric bearings requires some clarification. These forces are mobilised by actions such as thermal expansion or contraction, wind loading or earthquake response, and so it is the load factors associated with the actions causing bearing distortion that should be applied.

2.21 Construction forces and effects

2.21.1 Outline of coverage

Section 21 of AS 5100.2 sets out requirements for the consideration of:

- permanent forces and effects introduced during construction
- loads arising during the construction
- temporary structures.

2.21.2 Variation of requirements from the *Bridge manual*

AS 5100.2 requires:

- consideration of permanent forces and effects introduced during construction
- allowance to be made for the weight of falsework or plant arising from an anticipated construction method
- where a design is dependent on a particular method of construction, for the constraints to be included in the drawings and specification
- investigation of the ability of the structure to resist flood and wind during construction
- consideration of time-related relaxation of construction effects where appropriate
- design of temporary structures in accordance with appropriate standards.

The *Bridge manual* specifies the first two of the above, but not the others.

2.21.3 Suitability and actions required to enable adoption

The AS 5100.2 requirements are suitable for adoption without further modification.

2.22 Load combinations

2.22.1 Outline of coverage

Section 22 of AS 5100.2 categorises loads and load effects and specifies load combinations for consideration.

2.22.2 Variation of requirements from the *Bridge manual*

2.22.2.1 AS 5100.2 Categorisation of loads

AS 5100.2 categorises the loads and load effects as follows.

Permanent effects (PE):

- structure dead load
- additional permanent loads (superimposed dead loads)

- earth pressure
- normal water flow loads and buoyancy
- shrinkage and creep effects (zero and full effects)
- prestress effects (before and after losses)
- bearing friction or stiffness forces and effects
- differential settlement and/or mining subsidence effects.

Thermal effects:

- effects due to variation in average bridge temperature
- differential temperature effects.

Transient effects:

- vehicular traffic load, including dynamic effects
- pedestrian traffic loads
- wind loads
- earthquake loads
- flood loads including debris and impact loadings.

2.22.2.2 SLS load combinations

AS 5100.2 SLS load cases are derived as:

Permanent effects + one transient effect + k (one or more transient or thermal effects)

Where: k = 0.7 for one additional effect

= 0.5 for two additional effects.

This formulation is assessed to result in 180 load combinations, assuming no more than two additional transient or thermal effects are considered.

Bridge manual load combinations are given in table 2.9.

Table 2.9: *Bridge manual* serviceability limit state load combinations.

Group	Loads
1A	DL + EL + GW + EP + OW + SG + ST + CF +1.35 LLxI + FP
1B	DL + EL + GW + EP + OW + SG + ST + TP
2A	DL + EL + GW + EP + OW + SG + ST + CF + 1.35LLxI + FP + HE + TP
2B	DL + EL + GW + EP + OW + SG + ST + CF + 1.35LLxI + FP + HE + WD
2C	DL + EL + GW + EP + FW + PW + SG + ST + CF + 1.35LLxI + FP + HE
3A	DL + EL + GW + EP + OW + SG + ST + EQ + 0.33TP
3B	DL + EL + GW + EP + FW + PW + SG + ST + WD
3C	DL + EL + GW + EP + OW + SG + ST + CO + 0.33TP
4	DL + EL + GW + EP + OW + SG + ST + OLxI + 0.5FP + 0.33TP
5A	DL + EL + GW + EP + OW + SG + 0.33WD + CN
5B	DL + EL + GW + EP + OW + SG + 0.33TP + CN
5C	DL + EL + GW + EP + OW + SG + 0.33EQ + CN

2.22.2.3 ULS load combinations

AS 5100.2 ULS load cases are as follows:

- PE + ultimate thermal effects (+ serviceability traffic loads if they produces a more severe loading)
- PE + ultimate traffic loads (+ serviceability thermal effects if they produce an adverse effect)
- PE + ultimate collision load
- PE + ultimate pedestrian traffic loads
- PE + ultimate wind load (+ serviceability thermal effects if the produce an adverse effect)
- PE + ultimate flood load (+ serviceability traffic loads, if the structure will be open to traffic and they produce a more severe loading)
- PE + earthquake.

To enable comparison with *Bridge manual* load combinations, including their load factors for the adverse effect, and using the *Bridge manual* notation where applicable, these load combinations for a concrete structure are given in table 2.10.

Table 2.10 AS 5100.2 typical load combinations for loads acting adversely on a concrete structure.

(1.2DL + 2.0SDL + 1.5EP + 2.0OW + 1.2SG + 1.0PR + 1.3BF + 1.5ST) + 1.25TP + LLxI + CF + HE
(1.2DL + 2.0SDL + 1.5EP + 2.0OW + 1.2SG + 1.0PR + 1.3BF + 1.5ST) + 1.8LLxI + 1.8CF + 1.8HE + TP
(1.2DL + 2.0SDL + 1.5EP + 2.0OW + 1.2SG + 1.0PR + 1.3BF + 1.5ST) + CO
(1.2DL + 2.0SDL + 1.5EP + 2.0OW + 1.2SG + 1.0PR + 1.3BF + 1.5ST) + 1.8FP
(1.2DL + 2.0SDL + 1.5EP + 2.0OW + 1.2SG + 1.0PR + 1.3BF + 1.5ST) + WD_{ult} + TP
(1.2DL + 2.0SDL + 1.5EP + 1.2SG + 1.0PR + 1.3BF + 1.5ST) + k*FW + LLxI + CF + HE
(1.2DL + 2.0SDL + 1.5EP + 2.0OW + 1.2SH + 1.0PR + 1.3BF + 1.5ST) + EQ

*k, the flood flow ultimate limit state load factor, varies between 1.0 and 2.0 depending the return period of the event that provides the critical case for design.

Where notation is as defined in the *Bridge manual* clause 3.5, and additionally:

BF = bearing friction effects

PR = prestress effects

SDL = superimposed dead load

SG = shortening effects (excluding prestress effects in the case of AS 5100.2)

As a comparison, the *Bridge manual* ULS load combinations are given in table 2.11.

Table 2.11 *Bridge manual* ultimate limit state load combinations.

Group	Loads and load factors
1A	1.35(DL + EL + 1.35EP + OW + SG + ST + 1.67(CF + LLxI) + 1.30FP) + GW
1B	1.35(DL + EL + 1.35EP + OW + SG + ST + 1.25TP) + GW
2A	1.20(DL + EL + EP + OW + SG + ST + CF + LLxI + FP + HE + TP) + GW
2B	1.35(DL + EL + EP + OW + SG + ST + CF + LLxI + FP + HE) + GW + WD
2C	1.35(DL + EL + EP + SG + ST + CF + LLxI + FP + HE) + GW + FW + PW
3A	1.00(k*DL + EL + 1.35(EP + OW) + SG + ST + EQ + 0.33TP) + GW
3B	1.10(DL + EL + 1.25EP + SG + ST) + GW + FW + PW + WD
3C	1.00(DL + EL + 1.35(EP + OW) + SG + ST + 2.00CO + 0.33TP) + GW
3D	1.20(DL + EL + EP + OW + SG + ST + TP) + GW + PW + SN + 0.33WD
4	1.35(DL + EL + EP + OW + SG + ST + 1.10(CF + OLxI) + 0.70FP + 0.33TP) + GW
5A	1.35(DL + EL + EP + OW + SG + 1.10CN) + GW + 0.33WD
5B	1.35(DL + EL + EP + OW + SG + 0.33TP + 1.10CN) + GW
5C	1.35(DL + EL + EP + OW + SG + 0.33EQ + 1.10CN) + GW

*k is to be taken as either 1.3 or 0.8, whichever is more severe, when considering horizontal earthquake response, to allow for vertical earthquake response effects, and is to be taken as 1.0 when considering vertical earthquake response as the EQ loading.

2.22.3 Suitability and actions required to enable adoption

The AS 5100.2 approach to load combinations reduces the formulation to a simplistic mathematical process that appears to neglect to a fair degree a fundamental consideration of what loads are actually likely to coexist and to what extent.

For the SLS, from the perspective of what is practical, the number of load combinations to be considered requires the use of an automated computerised process.

For the ULS, AS 5100.2 adds one transient or thermal load to the permanent loads without consideration of what transient and thermal loads are likely to act concurrently. In four cases, a concurrent serviceability load is to be added where they result in a more severe effect. The likelihood of ultimate flood and wind loading acting concurrently, or of pedestrian loads acting concurrently with the ultimate traffic loading, is not considered in the AS 5100.2 ULS load combinations.

The *Bridge manual* considers a wider range of loads acting on the structure concurrently, including water ponding, ground water and snow loads in the load combinations.

A detailed investigation of the basis for the AS 5100.2 load combinations should be undertaken before their adoption is contemplated. On the surface, their formulation appears to be simplistic, and in the case of the SLS, impractical for manual application. If AS 5100.2 were adopted, supplementary documentation would need to incorporate the *Bridge manual* load combinations.

2.23 Road signs and lighting structures

2.23.1 Outline of coverage

Section 23 of AS 5100.2 includes the following:

- definitions of the limit states for these structures
- design wind speeds and wind loads
- design live loads on service walkways
- design load combinations, being a combination of the appropriate limit state dead load, wind load, and where appropriate, live load.

2.23.2 Variation of requirements from the *Bridge manual*

The *Bridge manual* does not present requirements for road signs or lighting structures as these are outside its scope.

2.23.3 Suitability and actions required to enable adoption

The design requirements set out in AS 5100.2 are generally suitable for adoption but it is recommended that the design wind speeds are reviewed and established following the philosophy and principles presented by AS/NZS 1170. AS/NZS 1170 is expected to be adopted by the Department of Building and Housing as an approved document under the NZBC and to form the basis for establishing compliance of design loadings with the building code. Alignment with AS/NZS 1170 is therefore seen as important for providing reasonable assurance that building consents for roading structures will be forthcoming.

2.24 Noise barriers

2.24.1 Outline of coverage

Section 24 of AS 5100.2 covers the derivation of and design for wind loading acting on noise barriers.

2.24.2 Variation of requirements from the *Bridge manual*

The *Bridge manual* does not present requirements for noise barriers as these are outside its scope.

2.24.3 Suitability and actions required to enable adoption

As for road signs and lighting structures, the design requirements set out in AS 5100.2 for noise barriers are generally suitable for adoption but it is recommended that the design wind speed is reviewed and established following the philosophy and principles presented by AS/NZS 1170.

2.25 Appendix A: Design loads for medium and special performance barriers

2.25.1 Outline of coverage

Appendix A of AS 5100.2 provides guidance on design loads and minimum effective height to be adopted for the design of medium and special performance barriers.

2.25.2 Variation of requirements from the *Bridge manual*

AS 5100's medium performance level corresponds to the *Bridge manual's* performance level 5, with only minor variation in the ultimate vertical downward load.

The lower of AS 5100's special performance levels corresponds reasonably closely to the *Bridge manual's* performance level 6, adopting slightly lower ultimate transverse and ultimate vertical downwards loads.

The higher of AS 5100's special performance levels is similar in loading to that of the *Bridge manual*, but it adopts a higher ultimate vertical loading (450 kN cf 380 kN). The guidance on minimum effective height is unclear, with 1400 mm suggested, but otherwise specified by the road controlling authority, whereas the *Bridge manual* indicates a range of 1700 to 2000 mm.

2.25.3 Suitability and actions required to enable adoption

The appendix is generally suitable for adoption. The differences from the *Bridge manual* requirements are relatively small. Clearer guidance on the effective height for the upper level special performance barriers would be helpful, but this performance level would not often be required and its use would probably be the subject of a special study.

3 AS 5100.3: Foundations and soil supporting structures

AS 5100.3 content

Table 3.1 lists the content of part 3 of AS 5100 (AS 5100.3) together with the comparable sections or clauses of the *Bridge manual*.

Table 3.1 AS 5100.3 content and comparable *Bridge manual* clauses.

AS 5100.3 content	Comparable *Bridge manual* clauses
1 Scope	Introduction
2 Application	
3 Referenced documents	4.8.2 Design standards 4.9.2 Design standards 4.14 References
4 Definitions	
5 Notation	Notation is defined in individual clauses as the notation arises
6 Site investigation	2.4 Site investigations
7 Design requirements	4.8 Foundations 4.9 Earth retaining systems 4.10 Design of earthworks
8 Loads and load combinations	3.4.12 Earth loads 3.5 Combination of load effects
9 Durability	2.1.7 Durability requirements 4.9.6 Earth retaining systems
10 Shallow footings	4.8 Foundations 5.5.7 Structure on spread footing foundations
11 Piled foundations	4.8 Foundations 5.5.6 Structure on pile/cylinder foundations
12 Anchorages	4.9 Earth retaining systems
13 Retaining walls and abutments	4.9 Earth retaining systems 4.11 Integral and semi-integral abutments 5.7 Earth retaining structures
14 Buried structures	4.12 Buried corrugated metal structures 5.7.4 Culverts and subways
Appendix A: Assessment of geotechnical strength reduction factors ($Ø_g$) for piles	4.8.3 Strength reduction factors for foundation design
Appendix B: On-site assessment tests of anchorages	4.9.6 Anchored walls

3.1 Scope

3.1.1 Outline of coverage

AS 5100.3 sets out the minimum design requirements and procedures for the design in limit state format of foundations and soil-supporting structures for bridges, subways of conventional size and form, and culverts not specifically covered by other standards.

The following are excluded:

- corrugated steel pipes and arches (covered by other standards)
- underground concrete drainage pipes (covered by other standards)
- reinforced soil structures.

3.1.2 Variation of requirements from the *Bridge manual*

The *Bridge manual* does not contain equivalent statements of scope for foundations or for the design of earth retaining systems.

The design of earthworks for approach embankments and cuttings is covered in the *Bridge manual*, but not included within the scope of AS 5100.3.

3.1.3 Suitability and actions required to enable adoption

Section 1 of AS 5100.3 is suitable for adoption should AS 5100.3 as a whole be accepted.

If AS 5100.3 were adopted supplementary documentation would be required to incorporate provisions for the design of earthworks.

3.2 Application

3.2.1 Outline of coverage

Section 2 of AS 5100.3 refers to:

- relevant authority requirements to apply for the design of foundations for overhead wiring structures for electrified railway lines
- loads to be applied are specified by AS 5100.2 together with earth pressures determined from this part
- general design procedures to be adopted for foundations and soil-supporting structures.

3.2.2 Variation of requirements from the *Bridge manual*

The *Bridge manual* does not contain equivalent statements of application for foundations or design of earth retaining systems.

3.2.3 Suitability and actions required to enable adoption

This section is suitable for adoption should the part as a whole be accepted.

3.3 Referenced documents

3.3.1 Outline of coverage

Section 3 of AS 5100.3 lists standards referred to within the part.

3.3.2 Variation of requirements from the *Bridge manual*

No requirements are specified in this section.

3.3.3 Suitability and actions required to enable adoption

Additions, and possibly some exclusions, may need to be made to this list of reference documents to incorporate those relevant to supplementary documentation that may be recommended to support the adoption of subsequent sections of this part. These references would be drawn from the references listed in section 4.14 of the *Bridge manual*.

3.4 Definitions

3.4.1 Outline of coverage

Section 4 of AS 5100.3 defines terms primarily related to ground anchor tendons.

3.4.2 Variation of requirements from the *Bridge manual*

No requirements are specified in this section.

3.4.3 Suitability and actions required to enable adoption

This section is suitable for adoption as is.

3.5 Notation

3.5.1 Outline of coverage

Section 5 of AS 5100.3 defines notation used in this part, cross-referenced to where it occurs.

3.5.2 Variation of requirements from the *Bridge manual*

No requirements are specified in this section.

3.5.3 Suitability and actions required to enable adoption

This section is suitable for adoption as is provided at least a section of AS 5100.3 in which the notation appears is adopted. Extension of the notation list may be required to incorporate any notation from supplementary documentation recommended to support adoption of subsequent sections of this part.

3.6 Site investigations

3.6.1 Outline of coverage

Encompassed in section 6 of AS 5100.3 are:

- general requirements for site investigation
- requirements for design investigations

The extent of investigations is left to the relevant authority to specify.

3.6.2 Variation of requirements from the *Bridge manual*

AS 5100.3 indicates the possible coverage of preliminary and design investigations and suggests the required minimum number of boreholes, the extent of boreholes, test pits and other in situ tests, and that the presence of ground water and its effects be investigated.

The *Bridge manual* requires the investigations to establish the characteristics of the surface and subsurface soils, their behaviour when loaded, the nature and location of any faulting, and the groundwater conditions. Site conditions and materials affecting the construction of the structure are to be determined.

Both standards require an investigation report to be produced. The *Bridge manual* goes further than AS 5100.3 in requiring interpretation of the available data by suitably qualified personnel and recommendation of foundation types and design parameters, and the need for proof testing, pilot hole drilling or other confirmatory investigations during construction.

Confirmation of site conditions during construction is overlooked by AS 5100.3, but is given some emphasis by the *Bridge manual*.

3.6.3 Suitability and actions required to enable adoption

The AS 5100.3 requirements are generally suitable for adoption but would require supplementary documentation to confirm Transit's requirements and would benefit from extension to include the additional requirements specified by the *Bridge manual*, including the requirements for confirmation of site conditions during construction.

3.7 Design requirements

3.7.1 Outline of coverage

Section 7 of AS 5100.3 outlines the general principles involved and procedures to be followed in designing for strength, stability, serviceability.

3.7.2 Variation of requirements from the *Bridge manual*

The *Bridge manual* does not set out a comparable overview of the principles of design for strength, stability, serviceability and durability of foundation and soil supporting structures, but does specify requirements in each of these areas.

Not covered in AS 5100.3, but included in the *Bridge manual* is the capacity design of foundations to resist forces induced in the structure by yielding elements developing their over-strength capacity during earthquakes. As noted previously in section 3.1.2, the design of earthworks is also omitted from AS 5100.3.

3.7.3 Suitability and actions required to enable adoption

Section 7 of AS 5100.3 is generally suitable for adoption provided the other sections referred to by which various aspects are determined are also accepted. However, supplementary documentation would need to be prepared, if AS 5100.3 were adopted, to incorporate requirements for the capacity design of foundations and for the design of earthworks.

3.8 Loads and load combinations

3.8.1 Outline of coverage

Section 8 of AS 5100.3 sets out the loads to be considered. In general the load combinations are taken from AS 5100.2. Section 8 identifies the variety of sources of soil induced loadings to be considered and taken into account, and the load factors to be applied to these soil loads and effects in design for strength and stability.

3.8.2 Variation of requirements from the *Bridge manual*

AS 5100.3 provides a comprehensive listing of all the possible sources of loads applied on structures through or from the soils.

In the evaluation of foundation settlements, AS 5100.3 requires the load combinations set out in AS 5100.2 to be considered, whereas the *Bridge manual* allows the effects of live load to be ignored unless the live load is sustained over a long period of time. The *Bridge manual* also requires the repetitive nature of live load to be considered where it has the potential to affect foundation performance.

For earth retaining systems, the *Bridge manual* requires consideration to be given to the interaction between the ground and the structure under static, dynamic, earthquake and construction conditions, not all of which are included in AS 5100.3

3.8.3 Suitability and actions required to enable adoption

Two aspects of this section are questioned:

- In the design of spill-through abutment columns, adopting a width of only twice that of the column as the width applying earth pressure to widely spaced columns is likely to result in un-conservative force actions.
- For soil supporting structures, where the loads are imposed predominantly from the soil, the loads for consideration of strength and stability are to be combined using a load factor of 1.0 for each load. AS 5100.2 clause 5.4, specifies load factors to be applied to the density of soil and groundwater in the derivation of ULS loads. This clause is not sufficiently clear and gives rise to the potential for those load factors to be ignored. It would be inappropriate for a load factor of only 1.0 to be adopted for strength and stability design.

If AS 5100.3 were adopted, review and amendment of these two aspects through supplementary documentation would be required.

Otherwise, this section of AS 5100.3 is generally suitable for adoption. Supplementary documentation would be required to clarify the loads and load combinations if those specified by AS 5100.2 were not adopted. Supplementary documentation is also recommended to incorporate the *Bridge manual* approach to consideration of settlement, and its requirement to consider dynamic and earthquake actions on earth retaining structures.

3.9 Durability

3.9.1 Outline of coverage

Section 9 of AS 5100.3 sets out durability requirements for structural components of foundations and soil supporting structures, covering timber, concrete, steel, piling slip layer coatings and other materials.

3.9.2 Variation of requirements from the *Bridge manual*

AS 5100.3 defines the durability design objectives as being to achieve:

- with appropriate maintenance, the specified service life
- the effectiveness of all the specified design criteria throughout the service life.

This is not unduly different to the *Bridge manual*, which in line with the NZBC provisions, requires structures to be sufficiently durable to ensure that without reconstruction or major renovation, they continue to fulfil their intended function throughout their design life.

AS 5100.3 prohibits the use of untreated timber unless permitted by the relevant authority; applies the durability requirements of AS 5100.5 'Concrete to the design of concrete components'; requires action to be taken to counter stray current effects, where present, from corroding reinforcement or buried steelwork; and specifies corrosion rates that may be adopted in the absence of site-specific data for the corrosion of bare steel. By comparison, the *Bridge manual* does not present equivalent requirements or guidance on the durability design of timber or steel components. The *Bridge manual*'s durability requirements for concrete components differ somewhat from those of AS 5100.3. These differences are discussed in the review of AS 5100.5.

For earth retaining systems, the *Bridge manual* presents specific requirements for the protection of anchors and soil nails against corrosion and to ensure their durability. These requirements are more explicit than those presented in AS 5100.3.

3.9.3 Suitability and actions required to enable adoption

Section 9 of AS 5100.3 is generally suitable for adoption. If AS 5100.3 were adopted without AS 5100.5 for concrete design, supplementary documentation would be required to reference the durability requirements for concrete structures. Corrosion protection provisions for anchors and soil nails would be best dealt with in the section on anchors.

3.10 Shallow footings

3.10.1 Outline of coverage

Section 10 of AS 5100.3 applies to all types of shallow footings such as pad, strip and raft foundations, where the footing is founded at a shallow depth so that the strength of the ground above the footing level does not significantly influence the bearing resistance.

Coverage is given in section 10 to the following:

- loads and load combinations
- general design requirements
- design for geotechnical strength and stability as affected by geotechnical strength
- design for structural strength
- design for SLS
- design for durability
- structural design and detailing
- materials and construction requirements.

3.10.2 Variation of requirements from the *Bridge manual*

AS 5100.3 provides stand-alone requirements and is quite comprehensive in listing the range of considerations to be taken into account, while the *Bridge manual* references a range of other documents as providing guidance on the design of foundations and earth retaining structures. These include the NZBC verification method B1/VM1 'Foundations', which provides methods for assessing bearing capacity and sliding resistance. AS 5100.3 does not provide this information.

Both AS 5100.3 and the *Bridge manual* give the strength reduction factors to be applied in the assessment of geotechnical capacities. Selection of the strength reduction factors to be adopted are in both cases based on the method of geotechnical strength assessment. In the case of AS 5100.3 the selection is also based on other factors such as comprehensiveness of the site investigation, sophistication of the analysis method, degree of construction control, consequences of failure and the primary nature of the loading (static or dynamic). The *Bridge manual* also presents a similar extensive list of additional considerations, encompassing most of those in AS 5100.3 and adding a few more. These strength reduction factors generally fall within similar ranges between the two standards, but with AS 5100.3 adopting lower values in some cases.

3.10.3 Suitability and actions required to enable adoption

The AS 5100.3 requirements appear to be generally suitable for adoption. However, if AS 5100.3 were adopted, some supplementary documentation would be needed to retain the references to appropriate design guidance provided in the *Bridge manual*.

For the issuing of building consents, territorial authorities are likely to adopt the NZBC verification method B1/VM4 as the benchmark. Where there are differences in the approaches or factors applied by AS 5100.3, advice will needed on how these differences may be resolved.

3.11 Piled foundations

3.11.1 Outline of coverage

Section 11 of AS 5100.3 sets out minimum requirements for the design, construction and testing of piled foundations. The provisions apply to axially and transversely loaded piles installed by driving, jacking, screwing or boring, with or without grouting.

Section 11 covers the following:

- loads and load combinations
- general design requirements for strength, serviceability and durability
- structural design and detailing for precast reinforced concrete piles, prestressed concrete piles, cast-in-place concrete piles and steel piles
- materials and construction requirements.

3.11.2 Variation of requirements from the *Bridge manual*

AS 5100.3 requires the loads and general design of piles to comply with AS 2159, one of the documents referenced by the *Bridge manual* as providing design guidance. Additionally, AS 510.3 specifies a range of further criteria to be met such as the following, which are not included in the *Bridge manual*:

- Permissible displacements are to be limited to less than what can be tolerated by the supported structure and services.
- Where materials other than concrete or steel are used for the pile construction, relevant standards for the material are to be applied unless specified otherwise by the relevant authority.
- Piles are to be designed to give resistance to design actions.
- Splices in piles are only to be used where unavoidable.
- Requirements are given for minimum dimension, concrete strength, reinforcement and detailing requirements for precast reinforced and prestressed concrete piles and cast-in-place piles.

- Steel piles are to have a minimum thickness of 10 mm at the end of their design life, allowing for corrosion.
- Requirements are given for minimum spacing between piles, and minimum edge distance and end distance when piles are cast into a pile cap.

The *Bridge manual*, on the other hand, includes requirements aimed at ensuring seismic resistance, including the following:

- The effects of liquefaction are to be taken into account when assessing the support provided to piles by surrounding soils.
- The effects of liquefaction-induced lateral spreading of the ground, and settlement are to be taken into account.
- The minimum tensile connection strength between piles and pile cap should not be less than 10% of the pile tensile strength.
- At the pile – pile cap junction, a steel shell is permitted to contribute to the shear resistance and confinement, but should be neglected in determining moment capacity
- The rotation of the pile cap inducing moment as well as axial load in groups of raked piles under lateral seismic loading should be taken into account.

3.11.3 Suitability and actions required to enable adoption

This section of AS 5100.3 is considered to be generally suitable for adoption, but would require supplementing with additional documentation to include the *Bridge manual* requirements for seismic resistance.

AS 5100.3 requires piles subjected to lateral loads and bending moment to be designed to provide a design resistance greater than or equal to the maximum serviceability and ultimate design action effects for a distance at least 2 m below the point where lateral support commences. The intent of this requirement is not at all clear. Except where the tops of piles are rigidly restrained against rotation at the base of the pier, the maximum design moments in piles usually occur at some distance below where the lateral support commences.

Related to this, a draft amendment to the *Bridge manual*, not yet formally adopted, proposes, under the earthquake resistant design requirements, that where plastic hinging may occur at depth in the ground, adequate confinement of the plastic hinge zone be provided for a distance of at least three times the pile diameter either side of the level of maximum moment. This should take into account the possible variability of the hinge level due to such factors as the variability in soil stiffness, variability in the depth of scour and liquefaction of soil layers.

A review is recommended of the capacity reduction factors at the top end of the range adopted by AS 2159; however, where covered in the NZBC verification method B1/VM4 they are generally in alignment. AS 2159 allows capacity reduction factors as high as 0.9, higher than those adopted for the flexural design of reinforced concrete in New Zealand and the appropriateness of this is questioned.

3.12 Anchorages

3.12.1 Outline of coverage

Section 12 of AS 5100.3 applies to any type of anchorage used to restrain a structure by transmitting a tensile force to a load-bearing formation of soil or rock.

Section 12 covers:

- loads and load combinations
- design requirements
- materials and construction requirements
- anchorage installation plan
- anchorage testing
- monitoring.

3.12.2 Variation of requirements from the *Bridge manual*

Much as for shallow footings, AS 5100.3 provides stand-alone requirements and quite a comprehensive listing of considerations to be taken into account. On the other hand, the *Bridge manual* requires the use of established design standards and references three for anchored walls, one for soil nailed walls, and a further reference for geosynthetic reinforced soil walls.

The *Bridge manual* requires anchored walls to be designed to ensure ductile failure of the wall under earthquake overload conditions. It also defines two classes of corrosion protection systems and provides a decision-tree procedure for determining which class, as a minimum, must be used.

AS 5100.3 requires proof load tests to be conducted either on test anchors prior to construction or on selected working anchors during construction to establish the capability of the anchor system to provide the required resistance. It then requires that acceptance tests should be conducted on all anchors. It also provides a method for deriving the characteristic anchorage resistance from the measured capacities. The *Bridge manual* requires pull-out tests to have been conducted on trial anchors prior to the final wall being constructed, then ‘suitability’ tests to be conducted on a selected number of initially installed production anchors, and acceptance testing of all anchors installed.

For soil nailed walls, the *Bridge manual* additionally specifies soil nailing only be carried out on drained slopes free of groundwater or with an adequate level of drainage to ensure the facing and soil nailed blocks are fully drained. Soil nailed walls are not to be used to support bridge abutments unless it can be shown that the deformations associated with mobilisation of soil nail capacities or earthquake can be tolerated by the bridge structure.

For reinforced soil walls, the *Bridge manual* additionally specifies that inextensible reinforcement is used for reinforced soil walls supporting bridge abutments or where limiting the deformation of the wall is critical. Geogrid may be used where abutments are piled and the design takes into account expected deformations of the wall system. The strength of connections between the soil reinforcement and the facing panels or blocks is also to exceed by a suitable margin the upper bound pull-out strength of the reinforcement through granular fill or the post yield overstrength capacity of the reinforcement, whichever is lower.

The *Bridge manual* also specifies requirements for the seismic performance of different forms of retaining wall including anchored, soil nailed and reinforced soil walls. These requirements are not covered by AS 5100.3.

3.12.3 Suitability and actions required to enable adoption

The AS 5100.3 requirements are generally suitable for adoption, but require clarification of the capacity reduction factors to be applied in design for strength. Reference is made to AS 5100.5 and AS 5100.6 for structural strength reduction factors, but these do not appear to be clearly defined in the sections covering anchorages. If AS 5100.3 were adopted its strength reduction factors would need to be reviewed and supplementary documentation prepared to clarify or amend these as appropriate.

The section on design for durability is not very specific on durability requirements, referring back to clause 9, which does not present any provisions specifically for anchorages. Again, if AS 5100.3 were adopted, supplementary documentation would need to be prepared incorporating the existing *Bridge manual* clause 4.9.6(e) requirements for the corrosion protection of anchors.

If AS 5100.3 were adopted, the requirements of the *Bridge manual* not currently included in this part for anchored, soil nailed and soil reinforced walls, as discussed in 4.13.2 above, would need to be incorporated through supplementary documentation.

3.13 Retaining walls and abutments

3.13.1 Outline of coverage

Section 13 of AS 5100.3 covers the following:

- loads and load combinations
- design requirements for strength and stability, calculation of earth pressures, eccentric and inclined loads, serviceability and durability
- structural design and detailing
- materials and construction requirements
- drainage.

3.13.2 Variation of requirements from the *Bridge manual*

Clause 7.4 of AS 5100.3 precludes instability due to sliding. The *Bridge manual*, by comparison, permits wall displacement under earthquake loading in some situations and within limits, and requires the structural design of abutments and walls to follow capacity design principles.

The *Bridge manual* categorises retaining walls into different types with a range of criteria specified for each type, in particular for earthquake resistant design which does not receive any specific attention in this section of AS 5100.3.

3.13.3 Suitability and actions required to enable adoption

Section 13 of AS 5100.3 lacks adequate criteria for the performance of abutments and retaining walls under earthquake. It is otherwise generally suitable for adoption subject to other parts referred to also being adopted. If AS 5100.3 were adopted it would require supplementary documentation to incorporate the categorisation of walls and seismic performance criteria presented in the *Bridge manual*. Supplementary documentation would also need to deal with references to other parts (eg AS 5100.5) should they not be adopted.

3.14 Buried structures

3.14.1 Outline of coverage

Section 14 of AS 5100.3 sets out requirements for the design of structures where soil and rock loads form a significant proportion of the total loads on the structure.

Coverage is given within section 14 to:

- loads and load combinations
- design requirements for strength, stability, serviceability and durability
- structural design and detailing
- materials and construction requirements.

3.14.2 Variation of requirements from the *Bridge manual*

AS 5100.3 requires the design of precast box culverts to comply with AS 1597. Otherwise the requirements given for all types of buried structures in the above listed areas are mostly relatively general in nature with no requirements specific to seismic design.

The *Bridge manual* coverage of buried structures is relatively minimal. It does not provide any specific requirements for box culverts other than for earthquake resistant design. For buried corrugated metal structures, design is to comply with the following relevant standards, not cited by AS 5100.3:

- AS/NZS 2041 Buried corrugated metal structures
- AS 1761 Helical lock-seam corrugated steel pipes
- AS 1762 Helical lock-seam corrugated steel pipes – design and installation
- AS 3703 Long span corrugated steel structures

For these structures, the *Bridge manual* also specifies a design loading distribution to simulate the pressure applied on buried structures from HN-HO-72 live loading, and requires the possible effects of earthquake induced ground deformation and liquefaction to be considered.

For culverts and subways, the *Bridge manual* explicitly does not require earthquake loads to be considered for small structures of maximum cross-sectional dimension < 3 m, but for larger structures varying approaches are specified dependent on the depth of soil cover and form of structure.

3.14.3 Suitability and actions required to enable adoption

Section 14 of AS 5100.3 is generally suitable for adoption but supplementary documentation would be needed to incorporate the *Bridge manual* requirements for earthquake resistant design of buried structures. Also, a review of the standards cited by the *Bridge manual* for buried corrugated metal structures to check their appropriateness for inclusion and consistency with AS 5100.3 is recommended. Should HN-HO-72 be retained as the design live load, supplementary documentation would be required to incorporate the *Bridge manual* pressure simulation for this loading on buried structures.

3.15 Assessment of geotechnical strength reduction factors for piles (appendix A)

3.15.1 Outline of coverage

Appendix A of AS 5100.3 is simply a replication of clause 4.2.2 from AS 2159.

3.15.2 Suitability and actions required to enable adoption

This appendix is encompassed in the observations made previously for pile foundations (section 3.11.3 above). Refer also to section 3.17.1.1 below for recommendations specifically related to strength reduction factors.

3.16 On-site assessment tests of anchorages (appendix B)

3.16.1 Outline of coverage

Appendix B of AS 5100.3 is classed as informative and sets out stressing procedures and assessment criteria for proof load and acceptance tests.

3.16.2 Variation of requirements from the *Bridge manual*

The *Bridge manual* does not directly present any comparable guidance, though it may be provided by referenced documents.

3.16.3 Suitability and actions required to enable adoption

This section is suitable for adoption.

3.17 Summary of AS 5100.3

3.17.1 Issues relevant to the AS 5110.3 as a whole

3.17.1.1 Strength reduction factors

Throughout this part geotechnical strength reduction factors tend to differ a little from one structural element type to another for the same methods of assessment of geotechnical strength. In some cases these factors include allowance for the design life of the structure (ie whether permanent or temporary) and allowance for the mode of behaviour (eg bearing failure or overturning, sliding or global instability).

It is usual to take the mode of behaviour into account in the strength reduction factors applied to material strength, but structure design life is normally taken into account in the design loading applied and the load factors assigned to the design loading.

If AS 5100 were adopted, a detailed review of the capacity reduction factors and load factors specified in AS 5100.3 would be required to ensure that the required safety index is satisfied.

3.17.1.2 Cross-referencing to other AS 5100 parts

AS 5100.3 contains numerous cross-references to other parts of AS 5100, eg AS 5100.2 and AS 5100.5, which may not be wholly adopted. If AS 5100 were adopted a detailed review and possibly supplementary documents would be required to ensure that issues covered by this cross-referencing are all appropriately captured.

4 AS 5100.4: Bearings and deck joints

AS 5100.4 content

Table 4.1 lists the content of part 4 of AS 5100 'Bridge design' (AS 5100.4) together with the comparable sections or clauses of the Transit NZ *Bridge manual*.

Table 4.1 AS 5100.4 content and comparable *Bridge manual* clauses

AS 5100.4 content	Comparable *Bridge manual* clauses
1 Scope	Introduction
2 Referenced documents	4.14 References
3 Definitions	4.7 Bearings and deck joints
4 Notation	4.7 Bearings and deck joints
5 Functions of bearings and deck joints	4.7 Bearings and deck joints
6 Loads, movements and rotations	4.7 Bearings and deck joints
7 General design requirements	4.7 Bearings and deck joints
8 Movement restraints	4.7 Bearings and deck joints
9 Alignment of bearings and deck joints	4.7 Bearings and deck joints
10 Anchorage of bearings	4.7 Bearings and deck joints
11 Loads resulting from resistance to movement	4.7 Bearings and deck joints
12 Elastomeric bearings	4.7 Bearings and deck joints
13 Pot bearings	4.7 Bearings and deck joints
14 Sliding contact surfaces	4.7 Bearings and deck joints
15 Mechanical bearings	4.7 Bearings and deck joints
16 Bearings subject to uplift	4.7 Bearings and deck joints
17 Deck joints	4.7 Bearings and deck joints
Appendix A: Tables of standard elastomeric bearing properties	4.7 Bearings and deck joints
Appendix B: Testing of elastomer, category 1 tests	4.7 Bearings and deck joints
Appendix C: Manufacturing tolerances for laminated elastomeric bearings	4.7 Bearings and deck joints
Appendix D: Testing of laminated elastomeric bearings	4.7 Bearings and deck joints

AS 5100.4 sets out the minimum design and performance requirements for bearing and deck joints for the articulation and accommodation of movements of bridge structures.

4.1 Status of adoption of AS 5100.4 for use in New Zealand

AS 5100.4 has previously been reviewed and adopted by the *Bridge manual* as the standard for the design and performance of bearings and deck joints, supplemented by additional requirements in section 4.7 of the *Bridge manual* as explained below. Cross-references within the supplementary requirements and the commentary presented in sections 4.2 and 4.3 below refer to clauses within the *Bridge manual.*

4.2 Supplementary requirements adopted for the application of AS 5100.4 in New Zealand

4.2.1 General

4.2.1.1 Section 4.7.1(a) Design code

The design and performance of bearings and deck joints should comply with AS 5100.4: 'Bearings and deck joints' except where modified in section 4.7 of the *Bridge manual*. Where there could be conflict between the requirements of AS 5100.4 and section 4.7, the latter takes precedence.

4.2.1.2 Section 4.7.1(b) Elastomeric bearings

Reference to elastomeric bearings should also include laminated elastomeric bearings fitted with a lead cylinder, commonly referred to as lead-rubber bearings, used for the dissipation of earthquake energy.

4.2.1.3 Section 4.7.1(c) Deck joints

The number of deck joints in a structure should be the practical minimum.

In principle, deck slabs should be continuous over intermediate supports, and bridges with overall lengths of less than 60 m and skews of less than 30° should have integral abutments. Deck joints might be necessary in larger bridges to cater for periodic changes in length.

4.2.2 Modifications and extensions to AS 5100.4 criteria for bearings

4.2.2.1 Section 4.7.2(a) Limit state requirements and robustness

Pot bearings are designed for both the serviceability and ultimate limit states. Elastomeric bearings should be designed for serviceability limit state (SLS) effects, with the bearing fixings and overall bridge structure stability checked at the ultimate limit state (ULS).

Particular consideration should be given to the robustness of bearings and their fixings to [prevent] damage or loss of stability due to earthquake actions.

4.2.2.2 Section 4.7.2(b) Design loads and load factors

Reference in AS 5100.4 'Bearings and deck joints' to design loads and load factors given in AS 5100.2 should be replaced by reference to chapter 3 of the *Bridge manual*.

4.2.2.3 Section 4.7.2(c) Anchorage of bearings

Bearings, other than thin elastomeric strip bearings less than 25 mm in thickness, should be positively anchored to the bridge structure above and below to prevent their dislodgement during response to the ULS design intensity or a greater earthquake unless the bridge superstructure is fully restrained by other means against horizontal displacement relative to the support. Reliance should not be placed on friction alone to ensure safety against sliding. The bearing restraint system for horizontal load should be designed to resist the full horizontal force transmitted by the bearing from the superstructure to the substructure.

For laminated elastomeric bearings, horizontal restraint should be provided by dowels or bolts engaging in thick outer shims within the bearing or by vulcanising the bearings to external plates fixed in position to the structure by bolts. External restraining cleats should not be used. Dowels should generally be located as close to the centre of the bearing (in plan) as practicable, to prevent them from disengaging due to deformation of the edges of the bearing under the high shear strain that might develop during a strong earthquake. Dowels, as a means of bearing lateral restraint, do not need to be removable to allow bearing replacement provided that the bridge superstructure can be jacked sufficiently to enable the bearings to be lifted, disengaged from the restraining dowels and slid out of position.

4.2.2.4 Section 4.7.2(d) Bearing set back from the edge of concrete bearing surfaces and confinement of bearing surfaces

Bearings should be set sufficiently far back from the edge of concrete bearing surfaces to avoid spalling of the corner concrete. Where bearing pressures are high, confining reinforcement should be provided to prevent tensile splitting of the concrete. Consideration should be given to the redistribution of pressure on the concrete bearing surface due to horizontal loads such as from earthquake action.

4.2.2.5 Section 4.7.2(d) Elastomeric bearings

Elastomeric bearings should conform with the requirements of either AS 1523 'Elastomeric bearings for use in structures' or BE 1/76 'Design requirements for elastomeric bridge bearings', except that steel reinforcing plates may be a minimum of 3 mm thick.

Wherever feasible, bearings should be chosen from those commercially available, but this does not preclude the use of individual designs where circumstances justify it.

Under service conditions that exclude earthquake effects, the maximum shear strain in a bearing (measured as a percentage of the total rubber thickness being sheared) should not exceed 50%. Under response to the ULS design intensity earthquake, plus other prevailing conditions such as shortening effects, the maximum shear strain should not exceed 100%.

In the design of elastomeric and lead-rubber bearings, the following should be given particular attention:

- In evaluating the stability against roll-over, consideration should be given to the sensitivity of the stability to an extreme earthquake, as safety factors can be rapidly eroded.
- In bridges with prestressed concrete superstructures and the spans either continuous or tightly linked, consideration should be given to the long-term effects of creep shortening of the superstructure due to the prestress on the bearings.

4.2.3 Modifications to AS 5100.4 criteria for deck joints

4.2.3.1 Section 4.7.3(a) General requirements

The maximum opening of a deck joint will generally be determined by earthquake conditions at the ULS. No limitation applies to the maximum design width of an open gap joint under these conditions.

4.2.3.2 Section 4.7.3(b) Design loads

Deck joints and their fixings should be designed at the ULS for the following loads in place of those specified by AS 5100.4:

- Vertical
  The vehicle axle loads defined in section 3.2.2 of the *Bridge manual* together with a dynamic load factor of 1.60. The ULS load factors to be applied should be 2.25 to an HN axle load and 1.49 to an HO axle load.

- Longitudinal
  The local vehicle braking and traction forces specified in section 3.3.1, combined with any force due to the stiffness of, or friction in, the joint. The ULS load factor applied to the combined force should be 1.35.

4.2.3.3 Section 4.7.3(c) Movements

- Deck joints should be designed to accommodate the movements due to temperature, shortening and earthquake specified in section 5.6.1(b) of the *Bridge manual*, and to otherwise satisfy the requirements of 5.6.1(b).
- Design for longitudinal movements should include the effect of beam end rotation under live load.

4.2.3.4 Section 4.7.3(d) Anchorage

The second paragraph of AS 5100.4, clause 17.4 should be replaced by the following:

Where the deck joint is attached by bolts fixing into a concrete substrate or screwed into cast-in anchor ferrules, fully tensioned high tensile bolts should be used. The spacing of the bolts should not be greater than 300 mm and the bolts should develop a dependable force clamping the joint to the concrete substrate, of not less than 500 kN per metre length on each side of the joint.

4.2.3.5 Section 4.7.4(e) Drainage

The AS 5100.4, clause 17.5 should be replaced by the following:

Deck joints should be watertight unless specific provision is made to collect and dispose of the water. Sealed expansion joints, where the gap is sealed with a compression seal, elastomeric element or sealant, are preferred.

Open joints, where the gap is not sealed, should be slightly wider at the bottom than at the top to prevent stones and debris lodging in the joint, and should include a specific drainage system to collect and dispose of the water. Such drainage systems should be accessible for cleaning.

The design of drainage systems should accommodate the movement across the deck joints of the bridge of not less than one quarter of the calculated relative movement under the ULS design earthquake conditions, plus long-term shortening effects where applicable, and one-third of the temperature induced movement from the median temperature position, without sustaining damage. Under greater movements, the drainage system should be detailed so that damage is confined to readily replaceable components only.

4.2.3.6 Section 4.7.3(f) Installation

Deck joints and the parts of the structure to which they are attached should be designed so that the joint can be installed after completion of the deck slab in the adjacent span(s).

4.2.4 Additional criteria and guidance for deck joints

4.2.4.1 Section 4.7.4(a) Joint type and joint system selection

Deck joints should be designed to provide for the total design range and direction of movement expected for a specific installation. The design engineer should consider the guidance provided by the UK Highways Agency publication (1994), BD33/94 ‘Expansion joints for use in highway bridge decks', with respect to the movement capacity of common joint types.

Acceptance of a proprietary joint system should be subject to that system satisfying the requirements of the *Bridge manual* and the additional project-specific performance requirements. The design engineer should specify all dimensional and performance requirements, including movement capacity, to enable manufacturers to offer joints that are best suited to meet the requirements.

The characteristics and performance history of a particular joint should be reviewed to determine the suitability of the joint for a specific installation. The design engineer should consider information provided in 'Performance of deck expansion joints in New Zealand road bridges' (Bruce and Kirkcaldie 2000) and 'Bridge deck joints' (Burke 1989), with respect to the performance history of deck joints.

Proprietary deck joint suppliers should provide a warranty on the serviceability of their joint/s for a period of 10 years after installation. The warranty should cover all costs associated with rectification of a joint, including traffic control costs.

4.2.4.2 Section 4.7.4(b) Joint sealing elements

Joint sealing elements (eg compression and elastomeric membrane seals, sealants) should be resistant to water, oil, salt, stone penetration, abrasion and environmental effects and should be readily replaceable. Compression seals should not be used in situations where concrete creep shortening and/or rotation of the ends of beams under live loading will result in decompression of the seal.

Sealants should be compatible with the materials with which they will be in contact. Irrespective of claimed properties, sealants should not be subjected to more than 25% strain in tension or compression. The modulus of elasticity of the sealant should be appropriate to ensure that, under the expected joint movement, the tensile capacity of the concrete forming the joint is not exceeded. The joint should be sealed at or as near the mean of its range of movement as is practicable. Base support for joint sealants should be provided by durable compressible joint fillers with adequate recovery and without excessive compressive stiffness.

Joint seals or sealant should be set 5mm lower than the deck surface to limit damage by traffic.

4.2.4.3 Section 4.7.4(c) Nosings

New bridges and deck replacements should be designed with a concrete upstand the height of the carriageway surfacing thickness and at least 200 mm wide between the deck joint and the adjacent carriageway surfacing. This is to act as a dam to retain the surfacing and to isolate the surfacing from any tensile forces imposed on the deck by the joint system.

4.2.4.4 Section 4.7.4(d) Asphaltic plug (elastomeric concrete) joints

Asphaltic plug joints are in-situ joints comprising a band of specially formulated flexible material, commonly consisting of rubberised bitumen with aggregate fillers. The joint is supported over the gap by thin metal plates or other suitable components. Except in retrofit applications where the existing structural configuration prevents these joint dimensional requirements being met, elastomeric concrete plug joints should be designed and specified to have a minimum thickness of 75 mm and a minimum width of bond with the structure on either side of the joint gap of 200 mm. Such joints should be designed by the supplier or the supplier's agent to take account of the predicted movements at the joint including rotation of the ends of the bridge decks to be joined due to traffic loads.

Where proposed for use in retrofit situations with dimensions less than those specified above, evidence should be supplied to Transit of satisfactory performance of the joint system under similar or more demanding traffic conditions with a similar joint configuration over periods of not less than five years.

4.3 Bridge manual amendment commentary

4.3.1 General

Adoption of AS 5100.4 for the design of bearings and deck joints was undertaken in the September 2004 amendment to the *Bridge manual*. The accompanying commentary sets out the following explanation for this amendment in respect to bearings and deck joints.

4.3.2 Bearings

4.3.2.1 General philosophy

Until now, the *Bridge manual* has contained limited criteria for bearings, requiring only that elastomeric bearings comply with AS 1523 or BE 1/76, are generally chosen from those commercially available, and are designed to be replaceable.

Bearings are one of the components of bridges most responsible for incurring maintenance costs. Internationally, design codes and bridge authorities have placed increasing emphasis on bearings, developing criteria for their use and design, with codes devoting significant sections to their specification.

In particular, in North America and the United Kingdom, the trend is towards eliminating bearings wherever possible and making the bridge structures integral. In these countries, corrosion of metal bearings will have been a particular problem due to the use of de-icing salts on their roads. This approach is not appropriate in New Zealand, where we have a highly developed precast concrete industry and extensive use is made of precast elements in bridge superstructures. Supporting these elements on bearings has provided a popular, convenient and economical solution in New Zealand bridge construction. Most New Zealand bridge construction has relatively short spans, allowing elastomeric bearings to be used, and resulting in few problems of corrosion of critical bearing components.

In this revision, particular focus has been placed on harmonising with Australian practice where possible, and on ensuring the robustness of bearings to the response of bridge structures to earthquakes.

4.3.2.2 Changes to section 4 of the Bridge manual

Section 4.7: Bearings and deck joints

AS 5100.4 presents extensive criteria for the design of bearings, and in general, these are considered to be appropriate for adoption. Where necessary, amendments to the AS 5100.4 criteria are proposed to suit local conditions. Design loads are consistent with those specified in section 3 of the *Bridge manual*.

Adoption of the AS 5100.4 criteria and the application of criteria for elastomeric bearings is given in clause 4.7.1. Amendments to the AS 5100.4 criteria and additional criteria are given in clause 4.7.2.

AS 5100.4 adopts criteria for the design of elastomeric bearings with significant differences from those presented in AS 1523 or BE 1/76, which, in the past, have provided satisfactory performance. Adoption of AS 5100.4's elastomeric bearing design criteria is not proposed until a detailed study can be undertaken to identify the effect and significance of the differences. It is understood that there is considerable dissension within the elastomeric bearing industry over the appropriate criteria for the design of elastomeric bearings, and that revision of AS 1523 has failed to eventuate because of this. Maximum permitted shear strains, not previously specified, are proposed for both normal service conditions and under response to earthquakes.

Experience from past large earthquakes has demonstrated bearings are particularly vulnerable to damage in such events. A number of criteria are proposed, aimed particularly at ensuring the robustness of bearings and their fixings to earthquake loading.

4.3.3 Deck joints

4.3.3.1 General philosophy

Studies have shown that deck joint deterioration is the most common maintenance problem affecting New Zealand road bridges. Deck joints are also a potential source of deterioration to the bridge structure itself where leaking joints can promote corrosion of underlying structural elements.

There is currently only minimal guidance for design, selection and installation of deck expansion joints in the *Bridge manual* and the aim of the amendment is to upgrade the design guidance for deck joints.

The amendment is based around adoption of AS 5100.4 with some modifications to reflect New Zealand specific practice and conditions. AS 5100.4 contains comprehensive requirements for deck joints which are generally complementary to those currently in the *Bridge manual*.

The *Bridge manual* currently considers deck expansion joints in section 4 'Analysis and design criteria' and in section 5 'Earthquake resistant design'.

4.3.3.2 Changes to section 4 of the Bridge manual

In the current *Bridge manual* (September 2004) deck joints have been amalgamated with bearings into section 4.7 'Bearings and deck joints'. In section 4.7 deck joints are covered under 4.7.1 'General', 4.7.3 'Modifications to the AS 5100: Bridge design, part 4: Bearings and deck joints criteria for deck joints', and 4.7.4 'Additional criteria and guidance for deck joints'.

Subsection 4.7.1: General

Clause 4.7.1(c) covers the requirement to minimise the number of deck joints in a bridge and, in some circumstances, to consider the use of integral abutments. This approach follows the international trend towards the elimination of deck joints by making the bridge superstructure continuous wherever possible to avoid problems associated with deck joints.

In drafting this clause, reference was made to the approach taken in BA 42/96 'The design of integral bridges (UK Highways Agency 1996).

Subsection 4.7.3: Modifications to the AS 5100: Bridge design, Part 4: Bearings and deck joints criteria for deck joints

A fundamental change to the AS 5100.4 bridge design standard requirements is the need to accommodate the effects of earthquake movement on deck joint performance. The effects of earthquake are considered in clauses 4.7.3(a) and 4.7.3(c) in terms of the maximum open gap and movement at the ULS.

In clause 4.7.3(b) the design loads have been modified to agree with New Zealand practice and nomenclature. An impact factor of 1.6 has been adopted in accordance with the AS 5100.4 standard to account for the high dynamic loads on deck joints.

A significant change is to the anchorage of deck joints. In clause 4.7.3(d), the bolts attaching deck joints into a concrete substrate are required to be fully tensioned high tensile bolts rather than lower grade bolts tightened to a percentage of their proof load. This removes the requirement to consider fatigue of the anchors.

A critical performance requirement for deck expansion joints and associated hardware is the control of deck drainage water. An unexpected finding of 'Performance of deck expansion joints in New Zealand road bridges' (Bruce and Kirkcaldie 2000) was the continued use of open deck joints. Clause 4.7.3(e) requires that deck joints are watertight and recommends the use of sealed expansion joints. Where open joints are used they are required to include a separate drainage system to collect and dispose of the water which will not be damaged as a consequence of earthquake movement.

Additional requirements for deck joint installation (clause 4.7.3 (f)) pertain particularly to the timing of deck joint installation. Otherwise, the process of deck joint installation is closely related to the type of joint being installed and it is recommended that the joint suppliers be responsible for their installation.

Subsection 4.7.4: Additional criteria and guidance for deck joints

This subsection has been added to address some of the deficiencies and performance issues that have been encountered with deck joints in New Zealand.

Clause 4.7.4(a) addresses the critical factors in designing and selecting appropriate joint types. This clause requires the design engineer to consider both movement capacity and performance history to determine the suitability of a joint for a particular installation. Useful references are provided to give guidance on both these factors. As a performance measure proprietary deck joint suppliers are required to provide a warranty on the serviceability of their joints for a period of five years after installation.

Clause 4.7.4(b) considers joint sealing elements and is broadly similar to the requirements of the AS 5100 bridge design standard. A principal requirement is that joint sealing elements must be readily replaceable as they are unlikely to achieve the design life of the bridge. Key changes include definition of the different joint sealing elements and consideration of the decompression of compression seals due to concrete creep shortening. The clause also includes specific design requirements for poured sealant joints.

Clause 4.7.4(c) describes the design requirements for a concrete nosing at the location of the deck joints.

Clause 4.7.4(d) considers asphaltic plug joints. These joint types have a good performance history when designed with suitable dimensions and applied in appropriate situations. Failures have been recorded where joint dimensions were inadequate and where rotation of the bridge deck ends under traffic loads were not accounted for. This clause specifies measures to avoid such failures. In retrofit situations, where the joint dimensions are less then those specified, proof of performance history with a similar joint configuration is required.

4.3.3.3 Changes to section 5

Deck expansion joints are currently considered in the *Bridge manual* under section 5.6 ‘Structural integrity and provision for relative displacement’, subsection 5.6.1 ‘Clearances’. No changes have been made to this subsection.

4.4 Summary of AS 5100.4

AS 5100.4 has already been adopted for application in New Zealand subject to the additional requirements set out in section 4.7 of the *Bridge manual*.

AS 5100.4 requirements for the design of elastomeric bearings were not adopted. A detailed study is recommended of this aspect. An Opus in-house investigation by H Chapman noted that there was significant variation in the approach adopted by various standards (AS 5100, BS 5400, AASHTO and Eurocodes), and significant uncertainty about which standards predicted the characteristics of bearings most accurately. Different specialists appear to favour different standards. The specified regime for testing stiffness, particularly in shear, is important and can significantly affect the nominal value of the shear stiffness of the bearing.