THE NEW JOINT AUSTRALIAN AND NEW ZEALAND DESIGN STANDARD FOR STEEL AND COMPOSITE BRIDGES AS/NZS 5100.6 - PART 6: STEEL AND COMPOSITE CONSTRUCTION

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ABSTRACT

This paper presents some of the innovations that are included within the new Bridge Design Standard for Steel and Composite Construction AS/NZS 5100.6, which will be the first harmonized standard between Australia and New Zealand for the design of bridges. As Chairs of the Committees responsible for AS/NZS 5100.6 and AS/NZS 2327, the authors of this paper present the challenges faced from the introduction concrete compressive strengths up to 100 MPa and quenched and tempered steels with a yield strength up to 690 MPa. Perhaps one of the most innovative aspects of this standard is the introduction of an appendix that provides design rules for steel products that are not manufactured to Australia and New Zealand standards. This appendix is underpinned by rigorous structural reliability analyses undertaken by Australian and New Zealand researchers, which included the present authors of this paper.

INTRODUCTION

This paper provides an overview of the new Australasian Bridge Design Standard for Steel and Composite Construction AS/NZS 5100.6 (2017). Building on earlier steel design standard harmonisation initiatives, such as the cold-formed steel structures standard AS/NZS 4600 (2005), AS/NZS 5100.6 is the first joint Australian and New Zealand design standard for bridges. It has been a catalyst for further harmonization activities in design standards for steel construction, such as the development of the new standard for steel and concrete composite buildings DR AS/NZS 2327 (2016). In the future, it is hoped that this work may lead to a harmonization of the existing AS 4100 (1998) and NZS 3404 (1997) into a joint Australian and New Zealand steel structures standard. The structure of the current Australasian structural steel standards follows that of many other international standards and is presented in Fig. 1.

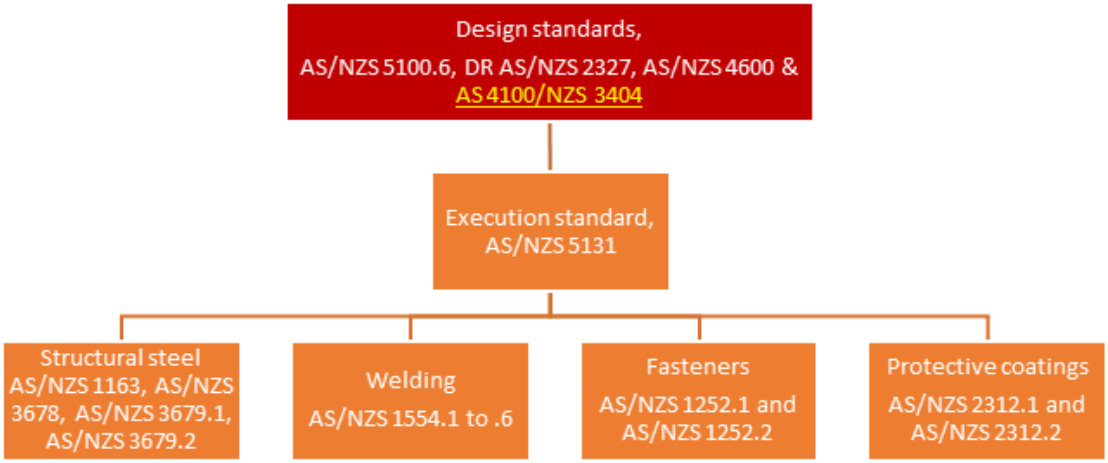


Fig. 1 - Current structure of Australasian structural steel standards.

Steel bridges have historically been used in both Australia and New Zealand. Two of the most iconic bridges in these countries are the Sydney Harbour Bridge (see Fig. 2(a)) and the Auckland Harbour Bridge: both of which used imported steel from Dorman Long, UK. Due to its limited domestic steel supply, New Zealand continues to use imported steel in many of its bridges such as the Te Rewa Rewa Bridge in New Plymouth shown in Fig. 2(b) (Mulqueen, 2011). The success of using imported structural steel in New Zealand is reflected in a market share of 50% for steel in construction, rising to 80% in Christchurch.

(a)

(b)

Fig. 2 - (a) Sydney Harbour Bridge, Australia (b) Te Rewa Rewa Bridge, New Zealand.

A number of technical and political challenges were presented in the development of AS/NZS 5100.6. On the technical side, the introduction of higher strength steel and concrete meant that many of the existing composite design provisions given in AS 5100.6 (2004) had to be reconsidered. In both technical and political terms, the requirement by New Zealand bridge designers to include steels manufactured to overseas standards resulted in reliability analyses being undertaken to demonstrate that the same margins of safety for designs using steels manufactured to AS and AS/NZS standards were maintained. Many of the other changes that will be presented in this paper drew on work that underpin the design provisions given in the structural Eurocodes (EN 1994-2 (2005) and EN 1993-1-9 (2005)) as well as AISC 360-16 (2016).

AS/NZS 5100.6 consists of 15 Sections and several Appendices. The structure is presented below in the following subheadings. Where significant changes have been made compared to the existing AS 5100.6, these are highlighted and an overview of the background work given

SECTION 1, 2 & 3 - SCOPE AND GENERAL, MATERIALS & GENERAL DESIGN REQUIREMENTS

AS/NZS 5100.6 is concerned with the design of structural steelwork in bridges together with steel-concrete composite members, including composite beams and composite columns. In addition, for consistency with the concrete bridges design standard AS 5100.5 (2017), concrete compressive cylinder strengths f'_c of up to 100 MPa are permitted. The standard applies to the design of other steel components of bridges including steel piers, steel railings and sign structures. The scope does not, however, include bridges with orthotropic plate decks, cold-formed steel members other than structural hollow sections, steel elements less than 3 mm thick nor steel members where the value of yield stress f_y > 690MPa. In a similar way as its predecessor, the structural steel product standards recognized are AS/NZS 1163 (2016), AS/NZS 1594 (2002), AS/NZS 3678 (2016), AS/NZS 3679.1 (2016) and AS/NZS 3679.2 (2016). However, the new addition is quenched and tempered steel plate produced according to AS 3597 (2008).

A design life of 100-years is assumed in the AS(/NZS) 5100: 2017 suite of standards. In a similar manner to North American practice, a global factor approach is adopted, where the design resistance is calculated by multiplying the nominal (characteristic) resistance by a capacity reduction factor ϕ (cf. partial factor approach, where $\phi = 1/\gamma_M$). Whilst this approach is simple to apply in structural steel and reinforced concrete design, it can prove problematical to apply in composite design as the equations for nominal capacity can consist of up to four different materials. As a consequence of this, the existing AS 5100.6 adopts a hybrid approach, where the capacity factors in composite columns are applied to the individual material components with ϕ = 0.9 for structural steel together with reinforcing steel and ϕ_c = 0.6 for concrete; this hybrid approach is maintained in AS/NZS 5100.6.

ALTERNATIVE STEEL PRODUCTS

According to AS/NZS 1170.0 (2002), it is based on the philosophy and principles set out in ISO 2394 (1998) (AS 5104 (2005) identical). In probability-based design, the probability of failure P_f is the basic reliability measure that is used. An alternative measure is the reliability index β and is related to the probability of failure P_f by:

$$P_f = \Phi(-\beta) \tag{1}$$

where Φ is the cumulative distribution function of the standardised normal distribution

The target reliability index is related to the expected social and economic consequences from a design failure. According to ISO 2394 and AS 5104, the suggested reliability index for ultimate limit state design is β = 3.8, which corresponds to the case when the consequence of failure is great (the highest level) and the relative costs of safety measures are moderate. Design values of resistances R_d are defined such that the probability of having a more unfavourable value is as follows:

$$P(R \le R_d) = \Phi(-\alpha_R \beta) \tag{2}$$

where α_R is the First Order Reliability Method (FORM) sensitivity factor for resistance.

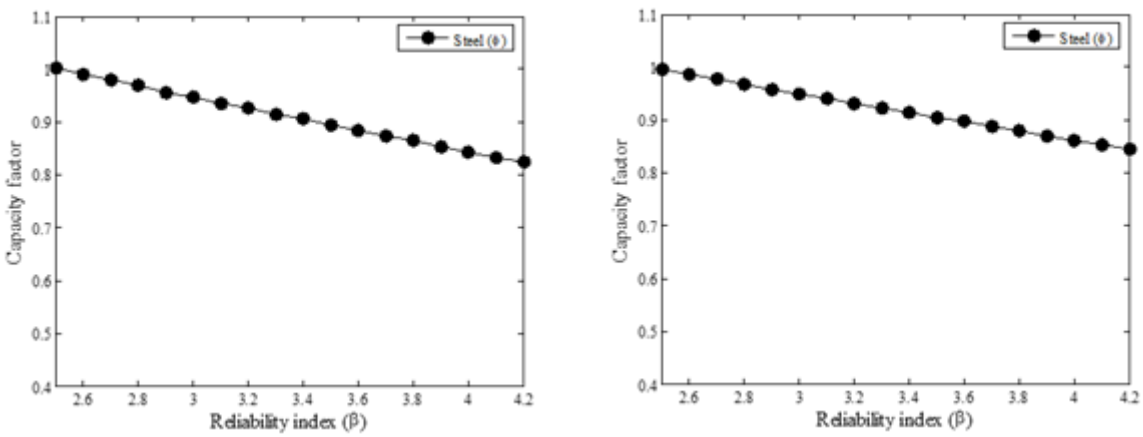
For a dominating resistance parameter, ISO 2394 and AS 5104 recommend α_R = 0.8. Therefore, the design value for resistance corresponds to the product $\alpha_R\beta$ = 0.8 × 3.8 = 3.04 (equivalent to a probability of the actual resistance falling below the design resistance of 1 in 845 = 0.0012). The remaining safety is achieved in the specification of actions.

In the interests of closer economic relations, the New Zealand Steel Bridge Group together with other key-stakeholders confirmed the wish to revise the Steel and composite bridge design standard AS 5100.6 as a joint AS/NZS document in 2012. Due to the long history of successfully using overseas structural steels with the design standard NZS 3404, it was required by New Zealand designers that steel products conforming to EN 10025 (2004), JIS G 3106 (2004) and JIS G 3136 (2005) should be supported by the resulting AS/NZS 5100.6. In response to concerns that the use of overseas steels might cause an erosion to the safety margins required by AS/NZS 1170.0, a structural reliability investigation was undertaken by Kang *et al.* (2015a), which considered both the material variability and geometric manufacturing tolerances.

Some typical results from the reliability analyses are presented in Fig. 3, which shows the relationship between the capacity factor ϕ and the reliability index β. As can be seen, for the target reliability index β = 3.04, the calibration results are almost identical within rounding errors, *viz.* the capacity reduction factor ϕ = 0.94, irrespective of the different manufacturing tolerances; this finding was confirmed in further structural reliability work on columns, composite

columns and composite beams, and was later shown by Uy *et al*. (2015) that it could also be safely extended to a wider range of steel products manufactured to Korean (KS), Chinese (GB) and American (ASTM) standards, which are currently recognized for design in Singapore by the Building and Construction Authority (BC1, 2012). Therefore, the existing capacity factor of ϕ = 0.90 given in AS 5100.6 for beams in bending is on the conservative side for steel sections complying with BS EN 10025, JIS G 3106 and JIS G 3136. This finding led to a proposed normative appendix to AS/NZS 5100.6 together with design rules for these alternative steel materials.

Unfortunately, on comparing the differences between the traceability and conformity requirements in the 2016 edition of the product standards (AS/NZS 1163, AS/NZS 3678, AS/NZS 3679.1 and AS/NZS 3679.2), the committee agreed that further work would need to be undertaken in the future to resolve these differences. Therefore, the rules for alternative steel materials are currently provided within a New Zealand-only appendix.



(a) ϕ=0.94 at β = 3.04 (b) ϕ=0.95 at β = 3.04

Fig. 3 - Capacity factor versus reliability index for compact sections using products complying with manufacturing tolerances given in (a) EN 10034 (1993) and (b) JIS G 3192 (2005)

SECTION 4 & 5 - METHODS OF STRUCTURAL ANALYSIS & STEEL BEAMS

Owing to the fact that finite element methods of analysis are now available in most engineering software packages, bridges are often being designed using these tools. However, there is a general paucity of information at a standards level on how different structures should be modelled. To remedy this situation, provisions are given in AS/NZS 5100.6 on modelling material behaviour in different types of analyses, together with required geometric imperfections.

One potential buckling mode that may occur when intermediate restraints are flexible is now recognized in AS/NZS 5100.6. The mode of buckling features one or two half wavelengths over the span, with the restraint positions in each half wavelength being displaced by the buckling. This mode occurs in multi-girder and ladder deck bridges during construction when there is no plan bracing; the only bracing is in planes (triangulated bracing or stiff cross-girders) between beam pairs. These planes offer torsional restraint to the main beams, by virtue of the vertical stiffness of the main beams themselves. The mode of buckling with torsional restraints is shown in Fig. 4, for a single half wave in a simply supported span (whilst the mode is illustrated with

stiff cross-girders, it can equally apply to beams with triangulated bracing). Once the deck slab has been cast, the cross-girders effectively form inverted U-frames and these may be used to provide some restraint to the bottom flanges adjacent to intermediate supports

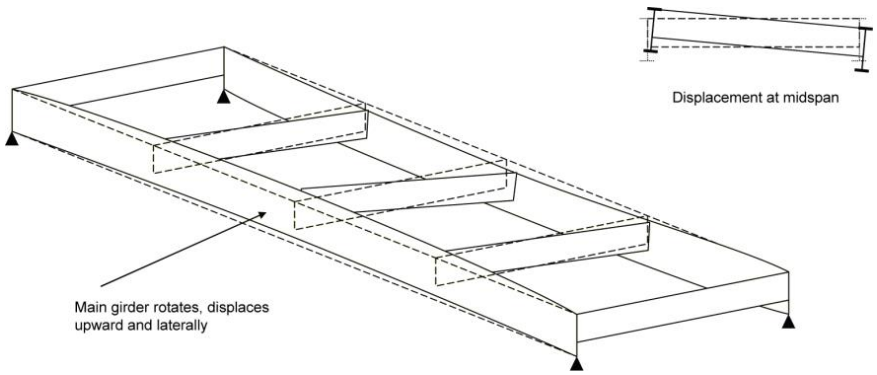


Fig. 4 - Buckling mode with intermediate torsional restraints

SECTION 6 & 7 - COMPOSITE BEAMS & COMPOSITE BOX GIRDERS

The most common form of shear connector in composite construction is the headed stud. A structural reliability study was undertaken specifically for AS/NZS 5100.6 (Hicks and Jones, 2013), which considered the results from 113 push tests. This work demonstrated that the following equations for the design shear capacity f_{ds} can be used for stud connectors embedded in solid concrete slabs and encasements:

$$f_{ds} = \phi 0.70 d_{bs}^2 f_{uc} \tag{3}$$

or

$$f_{ds} = \phi 0.29 d_{bs}^2 \sqrt{f'_{cy} E_c} \tag{4}$$

whichever is smaller.

where ϕ is the capacity reduction factor, which may be taken as $\phi = 0.8$ (previously given as $\phi = 0.85$ in AS 5100.6), d_{bs} is the nominal diameter of the shank of a stud connector, but 16 mm ≤ d_{bs} ≤ 25 mm; f_{uc} is the ultimate tensile strength of the stud material, but not greater than 500 MPa; f'_{cy} is the characteristic strength of the concrete at the age considered, but 16 MPa ≤ f'_{cy} ≤ 100 MPa; E_c is the modulus of elasticity of concrete at the age being considered, which may be taken as: $E_c = \rho^{1.2}\left(0.043\sqrt{f_{cmi}}\right)$ for f_{cmi} ≤ 40 MPa; or $E_c = \rho^{1.2}\left(0.024\sqrt{f_{cmi}} + 0.12\right)$ for f_{cmi} > 40 MPa, ρ is the density of concrete (kg/m³) and f_{cmi} is the mean value of the in situ compressive strength.

In AS/NZS 5100.6, Equation (3) has been extended to include high strength structural bolts as shear connectors. In these circumstances, the constant of 0.70 is replaced with 0.50.

From reliability analyses of 84 push tests using channel shear connectors, it was found that many of the international rules were on the unconservative side (Hicks *et al.*, 2016; CSA S16-09, 2009; AISC 360-16, 2016). To remedy this situation, the following equation for the design shear capacity f_{ds} was developed

$$f_{ds} = \phi 33.1\left(t_f + 0.5 t_w\right) L_{sc} \sqrt{f'_{cy}} \tag{5}$$

where t_f, t_w and L_{sc} is the flange thickness, web thickness and length of the channel shear connector in millimetres, respectively.

SECTION 8 & 9 – TRANSVERSE MEMBERS AND RESTRAINTS & MEMBERS SUBJECT TO AXIAL TENSION

Section 8 brings together the requirements for transverse members and restraints, and their design requirements, which are based on AS 4100 and NZS 3404. The Section also covers the requirements of AS 4100 and NZS 3404 for restraints to compression members.

Section 9 covers the design of members subject to axial tension forces that are statically loaded. Members subject to fatigue loading should also be assessed in accordance with Section 13 of AS/NZS 5100.6 (see below).

SECTION 10 & 11 - MEMBERS SUBJECT TO AXIAL COMPRESSION & MEMBERS SUBJECT TO COMBINED ACTIONS

In Eurocode 4, composite columns are limited to steel with a nominal yield strength of 235 MPa ≤ f_y ≤ 460 MPa and a concrete characteristic compressive strength of 20 MPa ≤ f'_{cy} ≤ 50 MPa. Through structural reliability work that considered an extensive database of 1583 test results by Kang *et al.* (2015b), it was found that the existing capacity factors of ϕ = 0.9 for the steel and ϕ_c = 0.65 for the concrete were justified for the design equations given in the existing AS 5100.6. However, it was also shown that the provisions for composite columns can be extended in AS/NZS 5100.6 to permit f_y values of up to 690 MPa and f'_{cy} values of up to 100 MPa.

SECTION 12 & 13 – CONNECTIONS & FATIGUE

According to Taplin *et al.* (2013), the design truck loading originally used in Australia was derived from the AASHTO H20-S16 combination, where the loading was increased by approximately 35% and the drive and trailer axles were replaced by tandem axle sets. Subsequent weigh-in-motion (WIM) data suggested that the average extreme daily events exceeded the load effects given by this design truck loading (Heywood, 1995). To remedy this situation, the SM1600 loading model was developed to ensure new bridges would possess sufficient resilience to future productivity enhancements in road transport. The SM1600 loading model represents the W80, A160, M1600 and S1600 traffic design loads in AS 5100.2 (2017). The A160 axle load and M1600 moving traffic load are presented in Fig. 5 (the S1600 static traffic load is similar to the latter, except that the UDL is increased to 24 kN/m and the 4 × 360 kN tri-axle set is reduced to 4 × 240 kN).

The fatigue loading provisions in AS 5100.2 (2017) are equivalent to the damage-tolerant method given in EN 1993-1-9 and the International Institute of Welding (Hobbacher, 2016) in that, although a 100-year design life is considered in the design of the bridge, the fatigue life is based on 75-years because of the following assumptions (AS 5100.2 Supp 1, 2007): the belief that bridges will be inspected regularly and that intervention will occur when fatigue damage is detected; and the uncertainty associated with the prediction of the fatigue life.

For road bridges, the current fatigue design traffic load effects are determined from 70% of the effects of a single A160 axle load (Fig. 5(a)), or 70% of the M1600 moving traffic load excluding the UDL (Fig. 5(b)), whichever is more severe. In both cases, a load factor of 1.0 is used and the load effects are increased by the dynamic load allowance α. The loads shown in Fig. 5 should be placed within any design traffic lane to maximize the fatigue effects for the component under consideration. When multiple traffic lanes are used, the current design approach is to undertake a Palmgren-Miner summation.

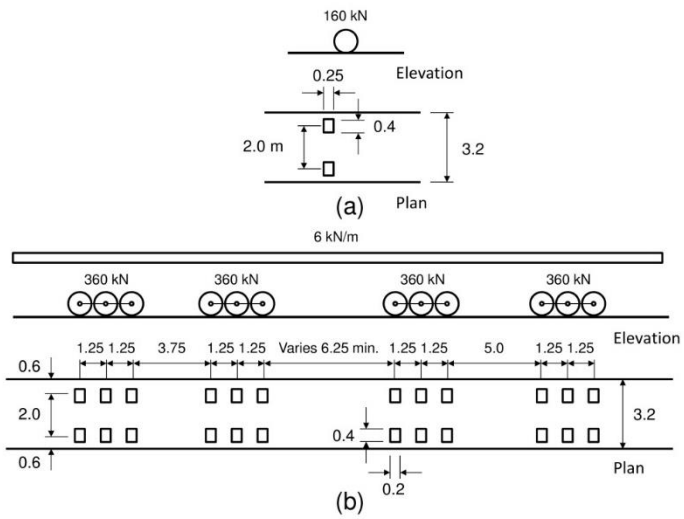


Fig. 5 - Road traffic loads according to AS 5100.2 (a) A160 axle load (b) M1600 moving traffic load (all dimensions in metres)

To provide greater alignment with international practice, AS/NZS 5100.6 has adopted the IIW provisions for fatigue design. In addition, to simplify bridge design, the damage equivalent approach from EN 1993-1-9 has been specifically developed for the loading given in AS 5100.2 (Hobbacher *et al.*, 2016), which has led to the following simple equation for fatigue verification of road bridges:

$$\gamma_{Ff}\Delta\sigma_{E,2} = \gamma_{Ff}\left[(1+\alpha)\lambda\Delta\sigma_{\max}\right] \leq \phi_{Mf}\Delta\sigma_c \tag{6}$$

where γ_{Ff} is the load factor for equivalent constant amplitude stress ranges (taken as γ_{Ff} = 1.0), $\Delta\sigma_{E,2}$ is the characteristic value of equivalent nominal stress range for 2 million cycles, α is a dynamic load allowance from AS 5100.2, λ is the damage equivalent factor (see Equation (6) below), $\Delta\sigma_{max}$ is the maximum stress range caused by the fatigue loads specified in AS 5100.2, ϕ_{Mf} is the capacity reduction factor (for high consequence of failure taken as: 0.85 for the 'damage tolerant' method, where there will be regular inspection; or 0.75 for the 'safe life' method, where there will be little/no inspection over the design life of the structure) and $\Delta\sigma_c$ is the fatigue resistance of the detail at 2 million cycles (the detail category).

The damage equivalent factor for road bridges is given by:

$$\lambda = \lambda_c\lambda_L\lambda_R\lambda_Y\lambda_M \tag{7}$$

where λ_c is for vehicles per day, λ_L is for consideration of span, λ_R is the route factor, λ_Y is the service life and λ_M is the effect of multiple lanes (if not yet covered in load assumptions).

A similar expression as Equation (7) is given for rail bridges and, for ease of use, the various damage equivalent factors are given in tabular form. For cases when the designer wishes to squeeze out the very last remaining capacity from a design or assess existing bridges, the Palmgren-Miner summation is supported within an appendix to AS/NZS 5100.6.

SECTION 12 & 13 – BRITTLE FRACTURE & TESTING OF STRUCTURES OR ELEMENTS

Given the introduction of quench and tempered steel plate, the steel types for brittle fracture have been extended to include AS 3597 products. Also, to remedy the unsatisfactory situation that the permissible service temperatures according to steel type and thickness are only appropriate for steels currently made in Australia or New Zealand, rules for evaluating the notch toughness of non-domestic steel products are given. It is hoped that these rules will be incorporated within AS/NZS 1163, AS/NZS 1594, AS/NZS 3678 and AS/NZS 3679.1 in due course.

CONCLUSIONS

Bridge design – Part 6: Steel and composite construction, is the only part of the AS 5100 suite of standards that has been revised as a joint AS/NZS standard. Overseas steels that have historically been used in New Zealand bridge design for the last 24 years are to be included in an appendix. Following the international trend of using less natural resources, design rules for higher strength steel and concrete are given. The new design rules within the proposed AS/NZS 5100.6 provide greater alignment with international best practice and, in some cases, significant improvements are given.

ACKNOWLEDGEMENTS

The authors would like to thank the members of the BD-090-06 Committee for all their hard work to date; in particular, the Standards Australia Project Manager, June Chen, responsible for Part 6 and the complete AS 5100 suite of standards. As members of the BD-090-06 Committee, the present authors have prepared this paper according to what they consider to be the significant changes to the existing AS 5100.6. However, the standard is still being prepared for public comment and, as a consequence of this, may be subject to change. Any views expressed in this paper may not necessarily reflect those of the other members of the Committee, nor those of Standards Australia and Standards New Zealand.

REFERENCES

ANSI/AISC 360-16. (2016). Specification for Structural Steel Buildings. American Institute of Steel Construction, Chicago, IL.

AS 3597 (2008). Structural and pressure vessel steel - Quenched and tempered plate, Standards Australia, Sydney, Australia.

AS 4100 (1998). Steel structures, Standards Australia, Sydney, Australia.

AS 5100.2 (2017). Bridge design, Part 2: Design loads, Standards Australia, Sydney, Australia.

AS 5100.2 Supp 1 (2007). Bridge design – Design loads – Commentary (Supplement to AS 5100.2 - 2004), Standards Australia, Sydney, Australia.

AS 5100.5 (2017). Bridge Design, Part 5: Concrete, Standards Australia, Sydney, Australia.

AS 5100.6 (2004). Bridge Design, Part 6: Steel and composite construction, Standards Australia, Sydney, Australia.

AS 5104 (2005). General principles on reliability for structures, Standards Australia, Sydney, Australia.

AS/NZS 1163 (2016). Cold-formed structural steel hollow sections, Standards Australia/Standards New Zealand, Sydney/Wellington, Australia/New Zealand.

AS/NZS 1170.0 (2002). Structural Design Actions, Standards Australia/Standards New Zealand, Sydney/Wellington, Australia/New Zealand.

AS/NZS 1594 (2002). Hot-rolled steel flat products, Standards Australia/Standards New Zealand, Sydney/Wellington, Australia/New Zealand.

AS/NZS 3678: 2016, Structural steel - Hot-rolled plates, floorplates and slabs, Standards Australia/Standards New Zealand, Sydney/Wellington, Australia/New Zealand.

AS/NZS 3679.1 (2016) Structural steel – Part 1: Hot-rolled bars and sections, Standards Australia/Standards New Zealand, Sydney/Wellington, Australia/New Zealand.

AS/NZS 3679.2 (2016). Structural steel – Part 2: Welded I sections, Standards Australia/Standards New Zealand, Sydney/Wellington, Australia/New Zealand.

AS/NZS 4600 (2005). Cold-formed steel structures, Standards Australia/Standards New Zealand, Sydney/Wellington, Australia/New Zealand.

AS/NZS 5100.6 (2017). Bridge Design, Part 6: Steel and composite construction, Standards Australia/Standards New Zealand, Sydney/Wellington, Australia/New Zealand.

BC1 (2012). Design guide on use of alternative structural steel to BS 5950 and Eurocode 3, Building and Construction Authority, Singapore, See http://www.bca.gov.sg (accessed 30/01/14)

CSA S16-09 (2009). Design of steel structures. Canadian Standards Association, Ontario.

DR AS/NZS 2327 (2016). Composite steel-concrete construction for buildings, Standards Australia/Standards New Zealand, Sydney/Wellington, Australia/New Zealand.

EN 1993-1-9 (2005). Eurocode 3: Design of steel structures – Part 1-9: Fatigue, European Committee for Standardization, Brussels, Belgium.

EN 1994-2 (2005). Eurocode 4: Design of composite steel and concrete structures – Part 2: General rules and rules for bridges, European Committee for Standardization, Brussels, Belgium.

EN 10025-1 *et seq*. (2004). Hot rolled products of structural steels, General technical delivery conditions, CEN, Brussels, Belgium.

EN 10034 (1993). Structural steel I- and H-sections – Tolerances on shape and dimensions, CEN, Brussels, Belgium.

Heywood, R (1995) Live loads on Australian bridges – statistical models from weigh-in-motion data. Australian Civil Engineering Transactions CE37(2), pp. 107–116

Hicks, S., Cao, J., McKenzie, C., Chowdhury, M. and Kaufusi, R. (2016). “Evaluation of shear connectors in composite bridges”, Research Report 602, NZ Transport Agency, Wellington, https://www.nzta.govt.nz/resources/research/reports/602/

Hicks, S. and Jones, A. (2013). “Statistical Evaluation of the Design Resistance of Headed Stud Connectors Embedded in Solid Concrete Slabs”. Structural Engineering International. 23(3), pp. 269-277.

Hobbacher, A. (2016). Recommendations for Fatigue Design of Welded Joints and Components, IIW Collection, Springer International, Switzerland.

Hobbacher, A.F., Hicks, S.J., Karpenko, M., Thole, F. and Uy, B. (2016). “Transfer of Australasian bridge design to fatigue verification system of Eurocode 3”. Journal of Constructional Steel Research, 122. pp. 532–542.

ISO 2394 (1998). General principles on reliability for structures, International Organization for Standardization, Geneva, Switzerland.

JIS G 3106 (2004). Rolled steels for welded structure, Japanese Standards Association, Tokyo, Japan.

JIS G 3136 (2005). Rolled steels for building structure, Japanese Standards Association, Tokyo, Japan.

JIS G 3192 (2005). Dimensions, mass and permissible variations of hot rolled steel sections, Japanese Standards Association, Tokyo, Japan.

Kang, W-H, Hicks, S, and Uy, B. (2015a). “Safety factors for the resistance of steel sections”. Australian Journal of Structural Engineering. 16(2). pp. 116-128.

Kang, W-H., Uy, B., Tao, Z. and Hicks, S. (2015b). “Design strength of concrete-filled steel columns”. Advanced Steel Construction. 11(2), pp. 165-184.

Mulqueen, P.C. (2011). “Creating the Te Rewa Rewa Bridge, New Zealand”, Structural Engineering International, 21(4). pp. 486-491.

NZS 3404.1 (1997). Steel structures standard, Standards New Zealand, Wellington, New Zealand.

Taplin, G., Deery, M., van Geldermalsen, T., Gilbert, J., Grace, R. (2013) “A new vehicle loading standard for road bridges in New Zealand”, Research Report 539, NZ Transport Agency, Wellington.

Uy, B., Hicks S. and Kang, W-H. (2015). “Australasian advances in steel & composite structures to enhance cross-border practice”. 17th ASEP International Convention (17AIC), Pasig City, Philippines.