Fiji Roads Authority

BRIDGE, CULVERTS AND ASSOCIATED STRUCTURES

(DESIGN GUIDE SUPPLEMENT TO AS 5100 BRIDGE DESIGN)

March, 2019

FRA's BRIDGE, CULVERTS AND ASSOCIATED STRUCTURES (Design Guide Supplement to AS 5100 Bridge Design)

Updates Record

Rev. No. Date Released	Section/s Update	Description of Revision	Authorised By
Rev 1 – 20 July 2018	Whole Document	Re-write of Bridge and Jetty Guide. Removal of Jetty and construction requirements	
Rev 3 – 5 Mar 2019	Minor Only	Following Workshops	

Acknowledgement: FRA gratefully acknowledges the generosity of the Association of Australian and New Zealand Transport and Traffic Authorities(Austroads) in allowing FRA, to use and reference much of the material used in this *Guide.*

Unless specifically identified in the *Guide*, all diagrams and tables have been sourced from the various VicRoads, NZTA and Austroads Design Guides and relevant Australian Standards.

CHAPTER TITLES

1 Scope

Fiji Roads Authority adopts the principles specified in the AS5100 Bridge Design Parts 1 to 9 and considers that these over-arching documents provide the framework for design and management of the bridges in Fiji.

This Design Guide Supplement to AS5100 Bridge Design to identify the documents that contain Fiji Roads Authority's requirements regarding a range of bridge-related issues including the design, assessment and management of bridges and associated structures. It is companion document to the Road Works Standards and Specifications and may or may not be referenced in the Standards and Specifications. The designer is expected to obtain copies of Design Guide to be read in conjunction with the following documents

- Road Works Standards and Specifications
- Standard Drawings
- Other relevant Fiji Roads Authority documents as applicable.

Compliance with Design Guide is mandatory.

This Design Guide was prepared to supersede Design Guide – Bridge, Wharf, Jetty, Culvert and Crossing Structures which published in 2015.

2 Purpose of Design Guide

Fiji Roads Authority prepares this Design Guide for several reasons:

- Specifies to designers how it requires the design of bridges and bridge components to be conducted to ensure, among other things, a standard approach to design that meets Fiji Roads Authority's requirements leading to standardisation of bridge performance and maintenance procedures
- To supplement Australian Standards
- Where Fiji Roads Authority requires a higher standard or an alternative approach to that which is stated in the Australian Standard
- Where it requires the use of a specific design detail
- Where it may wish to place restrictions on the use of certain components
- Where it is thought that additional guidance is required in order to clarify what is required in the Australian Standard
- To alert designers to issues arising from ambiguities in standards or incorrect application of standards.

3 Document Structures

Design Guide is a supplement document to AS5100 and provide the requirements for the assessment and management of bridges and associated structures.

Road Works Standards and Specifications is to provide the requirements for the testing, installing and manufacturing to be satisfied by a material, design, product or service.

Standards Drawing is to provide additional information on the standards and practices for typical details.

4 Hierarchy of Documents

The order of precedence of documents shall be as required by the contract. Supplements and documents listed in the Design Guide, Road Works Standards and Specifications and Standards Drawing shall take precedence over the AS5100.

5 Normative References

The following are the normative documents referenced in this Design Guide

AS 5100 (2017) Bridge Design
Part 1: Scope and general principles
Part 2: Design loads
Part 3: Foundation and soil supporting structures
Part 4: Bearing and deck joints
Part 5: Concrete
Part 6: Steel and composite construction
Part 7: Bridge assessment
Part 8: Rehabilitation and strengthening of existing bridges
Part 9: Timber

NZTA (2016) Bridge Manual – Third Edition

6 AS5100 Bridge Design (2017)

AS5100 provides consistently acceptable requirements for

- the design of road, rail, light rail, pedestrian and cyclist path bridges;
- the specific application of concrete, steel, timber and composite construction, which embody principles that may be applied to other materials in association with relevant Standards
- the assessment of the load capacity of existing bridges; and
- the rehabilitation and strengthening of existing bridges.

The requirements of the AS5100 is based on principles of structural mechanics and knowledge of material properties, for both the conceptual and detailed design, to achieve acceptable probabilities that the bridge or associated structure being designed will not become unfit for use during its design life.

AS5100 includes clauses intended to facilitate the specification to the designer of the functional requirements of the asset owner to ensure the long-term performance and serviceability of the bridge and associated structure.

AS5100.1 provides scope and general principles of bridge design and associated structures.

AS5100.2 specifies minimum design loads and load effects for road, rail, pedestrian and cyclist path bridges, and other associated structures.

AS5100.3 specifies the requirements and principles for the design of foundations for bridges and associated soil retaining structures.
AS5100.4 specifies the requirements for the design and selection of bearings and deck joints for bridges.

AS5100.5 specifies the requirements for the design and construction of concrete bridges and associated structures.

AS/NZS5100.6 provides design rules for steel and steel concrete composite bridges, or member within bridges.

AS5100.7 specifies the requirements for assessment of the geometry, condition, fatigue life, capacity and loading of existing bridges and associated structures, and to specify the method of calculation of the load rating factor of a bridge for a nominated rating vehicle.

AS5100.8 provides the requirements for the assessment of the load capacity, and for the rehabilitation and strengthening of existing bridges.

AS5100.9 provides the requirements for the design and construction of timber bridges and associated structures including members that contain steel connections. In addition, the Standard applies to the design of stress laminated timber decks for bridges.

7 Structure Definitions

Structure Type	Definition
Bridge	A structure, with the primary purpose of carrying a roadway or pathway over an obstacle, with a minimum span ≥ 1.8 m or a waterway area ≥ 3 m^2.
Major Culvert	A structure, with the primary purpose of providing a passageway beneath a road or path usually for the passage of water, with a minimum span or diameter ≥ 1.8 m or a waterway area ≥3 m^2.
Retaining Wall	A structure, with the primary purpose of retaining soil, that: • is greater than 1.5m in height and steeper than one horizontal to two vertical (63 degrees); or • is greater than 0.5m and in the event of structural failure would be a hazard to traffic, pedestrians or adjacent land-users, or would destabilise the road. The failure envelope shall be determined by projecting a 45 degree line from the toe of the retaining wall to top of the wall surface. Exclusions: • Walls within 30m of a bridge abutment is part of the bridge structure. If the wall length exceeds 30m, the remaining section shall be treated as a retaining wall and given a structure number and be subject to a separate inspection regime. • Walls at major culvert inlets, outlets and access ramps are part of the major culvert structure • Walls supporting road-related infrastructure for which Fiji Road Authrotiy is not the responsible road authority (service roads, footpaths and other) and walls constructed to support non-road infrastructure (adjoining properties, driveways, public transport infrastructure or other) • Landscaping treatments (feature walls, garden beds, beaching and paving and other)
High-mast lighting structure	Light poles with an overall height exceeding 17 metres.
Emergency bridging system	A demountable bridge used for emergency or temporary bridging comprising either a proprietary bridging system or other temporary structure.

8 Supplement to AS 5100 Bridge Design

8.1 AS5100 Part 1 Scope and general principles

This section states Fiji Roads Authority's general requirements of bridge design and associated structures.

Other than as stated in this Design Guide and other relevant Fiji Roads Authority standard specifications and technical documents, the provisions of AS5100.1 shall apply. Where the contents of this document and of Fiji Roads Authority's other relevant documents differ from AS5100.1, their requirements override those of AS5100.1.

8.1.1 Application

AS5100 shall not be used for design of bridges with spans greater than 100m, rail bridges for train speeds greater than 160km/h, or unusual or more complex bridges such as cable styed and suspension bridges.

8.2 AS5100 Part 2 Design Loads

This section states Fiji Roads Authority's requirements for the design loads and load effects for road, rail, pedestrian and cyclist path bridges, and other associated structures.

Other than as stated in this Design Guide and other relevant Fiji Roads Authority standard specifications and technical documents, the provisions of AS5100.2 shall apply. Where the contents of this document and of Fiji Roads Authority's other relevant documents differ from AS5100.2, their requirements override those of AS5100.2.

8.2.1 Design traffic loads for new bridges

The design traffic live loads for new bridges are SM1600, W80, A160 and HLP400 in accordance with AS5100.2 Clause 7. Any bridge utilised by Fiji Sugar Corporation (FSC) trains shall be designed in accordance with AS5100.2 Clause 9.

These design loads apply to all new road bridges and new culverts on declared main roads, except in unusual circumstances that have been accepted in writing by the Manager Design and Procurement.

8.2.2 Earthquake effects

Provision of earthquake resistant design of structures must comply in accordance with Clause 5 New Zealand Transport Agency Bridge Manual.

The designer must use the seismic hazard map below (Figure 1) as a reference.

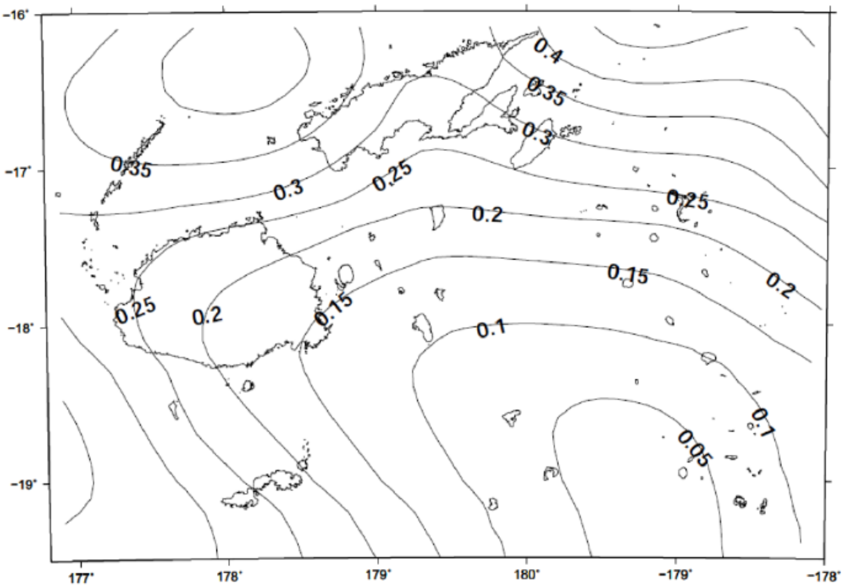

Figure 1: Seismic hazard map for Fiji

The minimum hazard factor, z=0.13 shall be adopted. Derivation of seismic peak ground acceleration (PGA) for geotechnical design shall be undertaken by calculating the zero period acceleration as defined by NZS 1170.5. An effective magnitude of 7.5 shall be adopted in conjunction with PGA.

8.2.3 Wind Actions

Wind loading shall be designed in accordance with Clause 17 of AS5100.2. The regional wind speed, V_R shall be used 70m/s and a wind direction multiplier $M_d = 1$.

8.2.4 Wave Actions

Wave action on bridges is not covered in AS5100 and if required, the wave actions shall be conducted by experienced person who has specialist knowledge in hydraulic and hydrologic areas.

8.3 AS5100 Part 3 Foundation and soil supporting structures

This section states Fiji Roads Authority's requirements for the design and specification of driven pile foundations for road structures. It states requirements for the design of precast concrete piles and steel piles (H-section and shell piles).

Other than as stated in this Design Guide and other relevant Fiji Roads Authority standard specifications and technical documents, the provisions of AS5100.3 shall apply. Where the contents of this document and of Fiji Roads Authority's other relevant documents differ from AS5100.3, their requirements override those of AS5100.3.

8.3.1 Materials

General

Reference shall be made to AS 5100, AS 2159, Fiji Roads Authority relevant technical documents and other relevant Australian Standards to determine the material properties to be used for design and manufacture of driven steel and precast concrete piles.

Other materials
Other materials shall comply with the appropriate Australian Standard or if no standard exists, the specification shall be approved by the Manager Design and Procurement.

8.3.2 Ground investigations

Extent of investigations
Further to AS5100.3 Clause 1.6.2, the minimum number of bore holes for bridges and major culverts shall be one borehole at every pier and abutment, with an additional borehole for each 10m of bridge width or part thereof.

High mast lighting poles shall have one bore hole per lighting pole. Gantries shall have one bore hole per leg of the structure.

For other structures (e.g. culverts, retaining walls, noise attenuation walls and similar), the minimum number of bore holes shall be one at each end and at intermediate locations at not more than 30m intervals.

The above are minimum requirements which may be increased depending on ground conditions subject to approval by the Superintendent.

8.3.3 Pile design

Concrete piles

Concrete Strength Grade
The minimum concrete strength grade for reinforced and prestressed concrete piles shall be 40MPa.

Concrete Cover
Minimum concrete cover shall comply with the requirements specified in AS5100.5 for the relevant exposure conditions, method of manufacture and concrete strength grade, except where specified otherwise in Table 1 below.

Table 1 Minimum cover to reinforcement

Exposure Classification as per AS 5100.5	Concrete Strength Grade		
	40MPa	50MPa	55MPa
(a) For piles cast in rigid formwork and intense compaction			
B1	45mm	40mm	40mm
B2	60mm	50mm	50mm
C1	NA	70mm	70mm
C2	NA	NA	80mm
(b) For piles manufactured by spinning or rolling			
B1	30mm	30mm	30mm
B2	35mm	30mm	30mm
C1	NA	40mm	40mm
C2	NA	45mm	45mm

Durability
Specific reference shall be made to the requirements of AS2159, AS5100.3, AS5100.5 and AS/NZS5100.6.

If steel, composite or jointed piles are used, the designer shall ensure that the geotechnical information includes a report on soil reactivity and ground water movement.

The following factors may influence durability of steel, composite or jointed piles and shall be assessed by the designer:

(a) Sites with possible electrolytic action due to stray currents, very low soil resistivity, high soil permeability or soils with very high or low pH
(b) If there is a proven occurrence of Sulphate Reducing Bacteria (SRB) or where soils have a pH-value above 9.5 or below 4.0.

Precast monolithic piles or individual segments of jointed piles shall be classified as members in water for the purpose of determining the exposure classification unless it is proven by geotechnical investigation that no part of the member is below the permanent water table.

Pile toe protection
Pile toes shall be protected to ensure that piles can be driven through hard materials without damage. The pile toe shall comprise a rock shoe, cast iron shoe, cruciform driving shoe or welded steel plate.

Welded steel plates shall not be less than 6mm thick.

Pile driving ring or head band
Pile driving rings shall be used to prevent splitting or bursting of the top of precast concrete piles during driving. Pile driving rings or head bands shall be fabricated using full penetration butt welds and backing plates.

Scour and pre-boring
If piles are located in a stratum that is at risk of scour damage, the potential effects of scour shall be included in the design of the foundations.

Unless a rigorous analysis is used, a minimum local scour allowance of 1.0m shall be used in addition to the general scour allowance.

When conducting a pile test to determine the loss of capacity due to scour, pre-boring to a level below the estimated scour depth shall be specified.

8.3.4 Axial capacity of driven piles

Acceptance criteria for pile driving
Dynamic testing and wave-equation analysis shall be used for all pile driving except if otherwise approved by the Superintendent.

Use of the Hiley formula to prove pile capacity may be permitted by the Superintendent for bridges of low significance (i.e. low traffic volume and small structures), if soil types are suitable and dynamic testing is not economically justifiable. If the Hiley formula is to be used, a geotechnical reduction factor of 0.4 shall be adopted irrespective of the requirements specified in AS2159.

8.3.5 Mechanical joints

Mechanical joints for precast reinforced concrete piles shall comply with the requirements of AS5100.3.

Mechanical joints shall not be located within 5 metres of the underside of a pile-cap or in aggressive groundwater – refer to Clause 8.3.3 Durability of this Design Guide. If aggressive groundwater is present, the location of splices shall allow for potential rise in water table due to seasonality.

The designer shall specify the allowable range of depths for the mechanical joints on the drawings.

8.4 AS5100 Part 4 Bearing and deck joints

This section states Fiji Roads Authority's requirements for the design and specification of bearings and deck joints for bridges.

Other than as stated in this Design Guide and other relevant Fiji Roads Authority standard specifications and technical documents, the provisions of AS5100.4 shall apply. Where the contents of this document and of Fiji Roads Authority's other relevant documents differ from AS5100.4, their requirements override those of AS5100.4.

8.4.1 Spherical bearings with approved sliding material

The supplier's name and proprietary bearing type shall be nominated on the drawings.

8.4.2 Restraint

Bearing restraints for elastomeric bearings shall:
provide restraint to the top and bottom of the bearing
be bolted to the bottom of the beam and to the bearing pedestal.

Use of dowels to restrain bearings is not permitted due to the difficulty this can cause if bearing replacement is required.

8.4.3 Bearing pedestals

Bearing pedestals must be designed in accordance with AS5100.5 and include reinforcement which is suitably spliced into the cross-head or abutment reinforcement.

Bearing Pedestals shall have 25mm chamfered edges.

8.5 AS5100 Part 5 Concrete

This section states Fiji Roads Authority's requirements for the design and assessment of reinforced and prestressed concrete structural members.

Other than as stated in this Design Guide and other relevant Fiji Roads Authority standard specifications and technical documents, the provisions of AS5100. shall apply. Where the contents of this document and of Fiji Roads Authority's other relevant documents differ from AS5100.5, their requirements override those of AS5100.5.

8.5.1 Methods of structural analysis

Strength of beams in shear and torsion
Modified Compression Field Theory in accordance with Clause 8.2 of AS5100.5:2007 may be used to determine the strength of reinforced concrete beams in shear and torsion. In some cases, Modified Compression Field Theory may not be the best used to determine the strength of prestressed beams in shear and torsion. In this case, the methodology of Truss Model Theory described in Clauses 8.2 and 8.3 of AS5100:2004 can be used.

8.5.2 Stress development of reinforcement and tendons

Compression reinforcement and secondary reinforcement
Mechanical splices may be used provided that:

- a proprietary connector is used; and
- the connector has appropriate dynamic capacity

If the structure containing the coupler could be subjected to dynamic loads, the time dependant properties of the coupler system must be established by testing for the effects of cyclical loading. The chosen coupler must perform satisfactorily over the design-life of the structure;

Tension reinforcement
Mechanical splices may not be used to join tension reinforcement in structures when the maximum permissible crack-width is less than 0.3mm.

Mechanical splices may be used to join tension reinforcement when the maximum permissible crack width is 0.3mm or more provided that:

- a proprietary connector is used in accordance with the manufacturer's recommendations
- not more than 50% of the total area of tensible reinforcement shall be mechanically spliced at any one section
- the splice is not placed at a position of maximum stress. For the purposes of this clause, the use of mechanical splices shall be restricted to those parts of the span at which the bending-moment causing the tensile stress in the reinforcement being coupled is not greater than 75% of the maximum bending-moment causing the tensile stress in the span being considered.

The following factors must be considered when selecting a coupler:

- minimum yield stress – the coupler system must be strong enough to develop the characteristic yield stress of the smallest diameter reinforcing bar in the connection
- dynamic capacity – if the structure containing the coupler could be subjected to dynamic loads, the time-dependent properties of the coupler system must be established by testing for the effects of cyclical loading. The chosen coupler must perform satisfactorily over the design-life of the structure
- tensile strength / yield stress ratio – to maintain the ductility of the structure, the Tensile Strength / Yield Stress Ratio of the coupler system should not be less than 1.08, measured for actual stress across the full range of yield stresses (500MPa to 650MPa for a grade 500N bar). Further consideration should be given to the tensile strength / yield stress ratio in designs for seismic conditions
- uniform elongation – a minimum uniform elongation of 3.5% is required for mechanical splices in order to maintain the ductility of the structure. Care should be taken when locating couplers to ensure the ductility of the structure is not reduced below the requirements of the design
- slip – slip in the coupler may lead to cracking in the concrete above the coupler. In order to limit the width of cracks in the concrete above the coupler to 0.3mm, slip in the coupler should be limited to 0.1mm at 67% of the yield load. The effects of shrinkage, creep and flexural cracking on the actual crack-width must be combined for this purpose
- the designer shall ensure that the performance of the selected coupler and the design of the reinforcement are consistent with the ductility of the reinforcement.

Cover to the connector
Where the external diameter of the connector is such that it will encroach into the cover zone, the designer must consider the following:

- the durability of the connector
- the minimum depth of concrete at the connector consistent with the maximum aggregate size of the concrete
- the effects on the strength of the reinforced concrete section should it be necessary to reduce the effective depth of reinforcement to achieve adequate cover to the connector.

Steel fibre-reinforced concrete
Steel fibre-reinforced concrete may not be the best used in the manufacture of structural components in both site and pre-casting processes. However, steel fibre-reinforced concrete may be used in the construction of non-structural reinforced concrete.

8.6 AS/NZS5100 Part 6 Steel and composite construction

This section states Fiji Roads Authority's requirements for steel and steel concrete composite bridges, or member within bridges.

Other than as stated in this Design Guide and other relevant Fiji Roads Authority standard specifications and technical documents, the provisions of AS/NZS5100.6 shall apply. Where the contents of this document and of Fiji Roads Authority's other relevant documents differ from AS/NZS5100.6, their requirements override those of AS/NZS5100.6.

8.6.1 Specific Requirements

Where AS5100.6 Clause 2.2 Structural Steel is unable to be addressed, Appendix H shall be adopted. Appendix J provides a commentary of the differences identified.

8.6.2 Corrugated Metal Structures

Corrugated steel plate culverts shall not be installed in locations where part of the culvert is below the watertable for extended periods.

In aggressive environments such as saline soil conditions, aluminium corrugated metal structures may be used subject to Fiji Roads Authority acceptance of the proposed material, manufacture, design and installation details, which shall be based on AS/NZS2041 modified to suit the properties of aluminium.

8.7 AS5100 Part 7 Bridge assessment

This section states Fiji Roads Authority's requirements for assessment of the geometry, condition, fatigue life, capacity and loading of existing bridges and associated structures, and to specify the method of calculation of the load rating factor of a bridge for a nominated rating vehicle.

Other than as stated in this Design Guide and other relevant Fiji Roads Authority standard specifications and technical documents, the provisions of AS5100.7 shall apply. Where the contents of this document and of Fiji Roads Authority's other relevant documents differ from AS5100.7, their requirements override those of AS5100.7.

8.8 AS5100 Part 8 Rehabilitation and strengthening of existing bridges

This section states Fiji Roads Authority's requirements for the assessment of the load capacity, and for the rehabilitation and strengthening of existing bridges.

Other than as stated in this Design Guide and other relevant Fiji Roads Authority standard specifications and technical documents, the provisions of AS5100.8 shall apply. Where the contents of this document and of Fiji Roads Authority's other relevant documents differ from AS5100.8, their requirements override those of AS5100.8.

AS 5100.8:2017 comprises separate sections covering:

- concrete structures
- steel structures
- timber structures
- masonry structures
- bearings
- deck Joints
- barriers
- culverts

It includes normative appendices covering:

- the design and application of fibre reinforced polymer (FRP) strengthening
- cathodic protection of reinforced concrete structures
- the design of rehabilitation or strengthening of timber structures.

8.8.1 BSALL loading

Proposals to evaluate and/or apply a Bridge Specific Assessment Live Load (BSALL) shall be determined by Fiji Roads Authority on a bridge-specific basis.

If Fiji Roads Authority specifies the requirement for a BSALL, the assessment methodology and resulting BSALL shall be subject to the approval of the Manager Design and Procurement.

8.8.2 Design of fibre reinforced polymer (FRP) strengthening of existing structures Structural assessment

FRP strengthening is permitted for use on structurally deficient reinforced and pre-stressed concrete structures. Structural assessment must be performed in accordance with AS5100 before the method of strengthening is selected and designed. The assessment must include a detailed bridge investigation, a review of existing design documents, drawings and a structural analysis.

The detailed bridge investigation must include the following:

- existing dimensions of structural members
- location, size and an assessment of the cause of cracks and other defects such as spalled areas
- quantity and location of existing steel reinforcement
- location and extent of corroded steel reinforcement
- compressive strength of concrete
- soundness of concrete and concrete cover in all areas where FRP is to be bonded to the concrete.

Strengthening with FRP composites is not suitable for use with structural components having a concrete strength less than 20MPa or greater than 60MPa.
If the characteristic strengths of the existing concrete, reinforcement or prestressing strand are not known, the designer must determine these parameters by testing.

If the investigation identifies that FRP is not a suitable means of strengthening, the designer must investigate other strengthening methods.

General design requirements
Attention is drawn to the corrections listed below

AS5100.8 Equation A6.5.1(4)

$T_f = E_f\, \varepsilon_f \leq f_{sy}$

The stress in the FRP should be limited to the stress in the steel. Therefore, the T_f, tension force in FRP equation should read as

$T_f = E_f\, \varepsilon_f \leq f_{fu}$

AS5100 Equation A7.2.3(4)
AS5100.8 gives the following expression for Le:

$$Le = \frac{23300}{(n_f\, t_f\, E_f)^{0.58}}$$

where

n_f is defined as the modular ratio of elasticity between FRP and concrete

Two errors exist:

- the units of E_f should be MPa not GPa
- n_f is is the modular ratio but should actually be n the number of plies of FRP reinforcement.

The equation should then read as follows:

$$Le = \frac{23300}{(n\, t_f\, E_f)^{0.58}}$$

where

n = number of plies of FRP reinforcement

AS5100.8 Equation A7.3.4(2)

E_f = modulus of elasticity for FRP (GPa)

The unit of E_f are given as GPa however MPa is used everywhere else in the document. The designer should take note and use the correct units consistently.

Design considerations
The designer must consider:

- the effect of sustained loads (creep)
- deterioration over time (design life)
- temperature effects
- fire risk and behaviour of FRP when exposed to high temperatures

Also, any other effect that might influence the strength, stiffness, installation methodology, safety and long-term maintenance implications of the strengthened structure.

Design life
The design life of FRP strengthening shall be at least the remaining life of the strengthened structure. Provisions for inspection, repair and maintenance during the design life shall be considered in the design.

Loading
Design loading for FRP strengthening at the serviceability and ultimate limit states shall be in accordance with the requirements of AS 5100.5.

Strength limit state - capacity reduction factors
The level of ductility of the strengthened reinforced concrete section shall be assessed in accordance with AS5100.8 Appendix A Clause. A6.3.2.

Similarly, for prestressed sections, the level of ductility shall be determined by checking the level of strain in the prestressing steel. If the strain in the prestressing steel at ultimate limit state exceeds 0.013, the section shall be considered ductile and a capacity reduction factor of 0.8 shall be applied. However, if the strain in the prestressing steel is less than 0.013, the capacity reduction factor must be reduced in accordance with equation 1 (below) where ε_{ps} is the net tensile strain in the prestressed steel at ultimate limit state.

$$\phi = \begin{cases} 0.80 \text{ for } \varepsilon_{ps} \geq 0.013 \\ 0.65 + \frac{0.15(\varepsilon_{ps} - 0.010)}{0.013 - 0.010} \text{ for } 0.010 < \varepsilon_{ps} < 0.013 \\ 0.65 \text{ for } \varepsilon_{ps} \leq 0.010 \end{cases}$$

… Eq 1

Accidental actions
Accidental actions such as fire or impact shall be considered in the design.

The fire endurance of FRP materials is low and the strength of FRP systems may be completely lost in a fire. If FRP is used to strengthen a structure, the design must ensure that the underlying structure remains serviceable in the event that the FRP is damaged by fire or high temperatures.

A bridge pier or column impacted by a vehicle requires sufficient strength (to withstand the impact) and ductility (to dissipate the energy).

When strengthening piers against impact, the following shall be included in the design:

- conservative equivalent static loading shall be used to ascertain flexural and shear demand
- shear strength enhancement to achieve the shear resistance shall be evaluated
- flexural strength enhancement shall be achieved through adding longitudinal FRP
- FRP in compression may be considered in design but only for circular piers and only in conjunction with transverse wrapping
- increase in strain capacity of concrete pier wrapped transversely may be considered in calculating flexural capacity but enhancement of concrete strength may be neglected.

Multi-layer laminate
The FRP strengthening systems available comprise pultruded plates and fabrics.

There are limitations to the thickness and number of layers of FRP that can be usefully employed. In this respect designs must take the following into consideration:

- the risk of a de-bonding failure of the FRP from the concrete (which will, in practice, limit the maximum usable thickness)

- use of two-layer laminates will approximately double the actual longitudinal shear stress in the FRP-concrete adhesive layer
- additional layers increase the number of potential failure modes since failure can occur in the adhesive between each layer which increases the risk of failure within the FRP.

For these reasons, the following limits shall be applied:

- pultruded plates maximum of 2 layers
- FRP fabrics maximum of 3 layers.

Flexural strengthening
Design for flexural strengthening shall comply with the requirements of AS5100.5 and AS5100.8.

FRP materials can be bonded to the tension face of beams or slabs to act as additional reinforcement, increasing the moment of resistance of the section.

FRP fibres must be parallel to the direction of the maximum tensile stress.
The design concept for flexural strengthening with FRP is essentially an extension of existing flexural strength theory with appropriate limit checks to account for possible FRP-induced failure modes. The flexure failure modes that can occur for an FRP-strengthened section are given below:

- crushing of the concrete in compression prior to yielding of the flexural reinforcing steel
- yielding of the flexural reinforcement followed by FRP rupture
- yielding of the flexural reinforcement followed by concrete crushing
- shear/tension delamination of the concrete cover (cover delamination)
- FRP de-bonding from the concrete substrate.

If the failure mode governing the design cannot easily be identified, the strengthened section shall be checked for each of the above failure mechanisms and the worst case shall be assumed for design purposes.

Shear strengthening
Structures strengthened with FRP to increase shear capacity can fail due to separation of the FRP from the concrete. The probability of this failure mode is reduced if a beam is fully encased in FRP.

Shear strengthening shall be achieved by wrapping FRP completely around a beam.
However, if this is not possible (e.g. beam and slab bridges), the FRP wrapping shall be applied to the sides and either the top or underside of a beam.
If it is not possible to wrap the FRP completely around a beam, consideration shall be given to the use of an FRP anchorage system. If an anchorage is required, it shall comply with the requirements of Section 6 below.

Anchorages
FRP anchorage systems for externally bonded FRP are used to:

- prevent or delay interfacial cracks from opening (de-bonding of the FRP from the concrete substrate or adjacent FRP layer)
- maximise the added interfacial shear stress capacity
- provide a stress-transfer mechanism if insufficient bond-length is available beyond the critical section.

The performance of anchorage systems becomes critical in the design of FRP strengthening systems because inadequate anchorage limits the strength of the FRP system.

The only published guidance that currently exists for anchorage systems deals with transverse wrapping. If it is intended to use other anchorage systems, the design strength of the proposed system must be evaluated by testing that includes the following:

- anchorage type
- size
- number of anchors
- geometrical arrangement of anchors
- installation procedure
- surface preparation
- ambient conditions during installation.

Full details of the proposed design, testing methodology and testing results shall be submitted to the Manager Design and Procurement for evaluation and approval.

Requirements for design and proof engineering
FRP strengthening shall be designed and proof engineered by an experienced person who has specialist knowledge of FRP materials and design methods.

8.8.3 Bridge Widening and Strengthening
Requirements for widening and/or strengthening of bridges shall be determined by Fiji Roads Authority on a bridge-specific basis.

Fatigue Cracking
Remediation of existing fatigue cracks
Fatigue cracking can occur where stiffening or bracing members are connected to principal load-carrying members rather than as a result of primary stresses in principal load carrying members. Fatigue cracks can result in a reduction in the capacity of principal load-carrying members.

AS 5100.8 Section 4 provides advice on the causes of fatigue cracking and repair of fatigue cracks.

Contrary to AS5100.8 Clause 4.5.4 (which requires that if a fatigue crack occurs, a hole is to be drilled through the tail of the crack to terminate it and evenly distributed the stress to a larger area), an investigation shall be conducted to understand the cause of the fatigue cracking before any remedial work is conducted. When the cause has been identified (commonly a stress concentration), a remediation solution shall be developed which may include modifications to alter load-paths and improve the flow of stresses.

Remediation of existing details
AS/NZS 5100.6:2017 includes more detailed provisions for assessment of fatigue life than are included in AS/NZS5100.6.

However, a calculation of fatigue life has a relatively high level of uncertainty.
Options for treating the cause of the fatigue cracking shall be identified and assessed. Such options can be compared by finite element analyses, adopting a suitable fatigue load spectrum and detail and, if necessary, by applying the hot spot stress method (ref International Institute of

Welding document IIW-1823-07 and Eurocode 1993-1-9) which will provide an approximate estimate of fatigue life treatment. The order of magnitude by which the detail is improved, as measured by the improvement in fatigue life, shall be used to select the treatment option that provides the greatest improvement in fatigue life.

Assessment of existing details
The AS 5100.8 approach to fatigue life assessment requires assumptions to be made regarding the fatigue load spectrum that will reduce the reliability of the result.

When assessing the fatigue life of an existing detail, the following approach may be used:

- conduct finite element analysis of the detail using a refined mesh at the detail of concern and applying a notional load of say 100kN
- using the Paris Law (which is based on linear elastic fracture mechanics) to determine the stress intensity factor (SIF) for the detail
- determine the fatigue strength for a notional number of cycles, e.g. 2 million cycles, using the SIF derived above
- instrument the bridge in a way that will provide the fatigue load spectrum for the detail concerned. This step may require a degree of extrapolation to determine the stress at the critical point
- derive an equivalent stress range of constant amplitude equivalent to the measured variable amplitude damage for the total number of actual stress cycles by application of the Miner's summation
- estimate the fatigue life using the fatigue strengths determined from the finite element analysis and the equivalent stress range derived from the recorded strains.

The foregoing analysis provides an estimate of fatigue life within an order of magnitude. It can be used to guide inspecting engineers where to look for the first signs of fatigue cracking.

For inspection purposes, consideration should be given to employing phased array ultrasonic methods rather than manual ultrasonic methods as a more robust, verifiable and reproducible method of non-destructive testing.

8.9 AS5100 Part 9 Timber

This section states Fiji Roads Authority's requirements for the design and construction of timber bridges and associated structures including members that contain steel connections. In addition, the Standard applies to the design of stress laminated timber decks for bridges.

Other than as stated in this Design Guide and other relevant Fiji Roads Authority standard specifications and technical documents, the provisions of AS5100.9 shall apply. Where the contents of this document and of Fiji Roads Authority's other relevant documents differ from AS5100.9, their requirements override those of AS5100.9.

8.9.1 Selection

Structural timber in Fiji is graded in accordance with the National Grading Rules for Fiji Timbers and using F-Grades which is consistent with AS5100.9.

Treated Fiji Pine is the preferred selection for new timber material. Where treated Fiji Pine does not meet the strength requirements, hardwood shall be used.

9 Other Structures

9.1 Large box culverts

This section states Fiji Roads Authority's requirements for the design of culverts and link slabs from 1500mm span to 4200mm span and 4200 mm in height. This section does not cover the design or manufacture of the box culverts covered by AS1597.1. This section is to be read in conjunction with AS1597.2 Precast reinforced concrete box culverts Part 2: Large culverts (exceeding 1200 mm span or 1200 mm height and up to and including 4200 mm span and 4200 mm height).

Designers should note that culvert units may be designed for the passage of water, vehicles, pedestrians or animals and that these should be designed with appropriate clearances, finishes and lighting if required.

9.1.1 Materials

Concrete
Concrete shall be in accordance with Road Works Standards and Specifications. The minimum concrete grade shall be 40MPa.

Durability
The minimum exposure classification for standard culvert units shall be B1.
Precast culvert units designed for use in livestock underpasses shall be designed for exposure classification C1.

Cover
The minimum cover shall be as specified in AS5100.5 for the appropriate exposure classification. Tolerance on cover shall be as specified in AS1597.2 Table 2.7.

Foundation material
Foundation material properties used for the design of U-shaped and one-piece culverts for a particular site shall be determined from a suitable geotechnical investigation.
If a geotechnical investigation has not been completed or the design is intended to cover standard culvert units, the foundation material shall be assumed to be a soft clay.

9.1.2 Design

Designs shall be completed by a suitably experienced engineer. Design shall be in accordance with AS1597.2 and AS5100 Bridge design. No reference shall be made to other Standards.

Design life
Culvert units shall have a design life of 100 years.

Design loads
Culvert units shall be designed using the requirements and design loads specified in AS 1597.2, Section 3 except that the W80, A160 and M1600 traffic loads specified in AS5100.2 (including dynamic load allowance) and as described below, shall be used.

Live loads W80, A160 and M1600
Culvert units shall be designed for the W80, A160 Axle Load and M1600 moving traffic load, detailed in AS5100.2. The dynamic load allowance factor as specified in AS5100 with appropriate load factors shall be used for these loads. The methods described in AS1597.2 Clause 3.3 is to be used to determine vertical and horizontal pressures due to these loads.

Site-specific loads
Culvert units shall be designed for site-specific loads such as barrier loading on end walls, wingwall loads and settlement of foundations.

Handling
Provision shall be made for lifting and handling the culvert units in accordance with AS5100. Lifting devices and methods of handling shall be determined by the designer.

Strength
The theoretical design strength φR_u shall be determined in accordance with AS5100.5. The critical section for shear shall be as shown in AS1597.2 Figure 3.2.

Serviceability
Serviceability parameters shall be calculated in accordance with AS 5100.5. However, the minimum distribution reinforcement shall be in accordance with AS 1597.2 Cl3.5.

Reinforcement detailing
Reinforcement detailing shall be in accordance with AS5100.5.

Hydraulic requirements
If culverts are designed for conveying water, the culvert walls shall present a smooth continuous surface to the water flow to prevent entrapment of debris.

Settlement
If one-piece culvert units are used, their bases shall be connected by shear keys designed to prevent differential settlement between adjacent units.

Shear keys in the base slab of culverts carrying water shall be sealed to prevent leakage.

9.1.3 Load testing for design

Proposals for verification of product compliance that rely on the provisions stated in AS1597.2 Appendix B (informative) shall be submitted to the Manager Design and Procurement for acceptance stating full details of the basis for the proposal. The Manager Design and Procurement may request further information if required.

9.2 Integral and Semi Integral Bridges

9.2.1 Terminology

The terms integral bridge and jointless bridge are sometimes interchanged. However, the following meanings apply in this document:

Integral Bridges feature a fully continuous moment connection between the superstructure and substructure at the abutments eliminating the need for joints or bearings to accommodate rotations and displacements at the ends of the deck.

Semi-integral Bridges form do not have deck joints but incorporates bearings at the supports. This form may be adopted when ground conditions are not suitable for a fully integral bridge.

In both cases, horizontal forces in the superstructure are transmitted to the abutment fill by a diaphragm that is continuous with the superstructure.

Jointless Bridge describes a bridge with a continuous deck (i.e. without deck joints) over the intermediate piers but which has movement joints and bearings at the abutments.

In multi-span integral or semi-integral bridges, the deck is made continuous between abutments and there are no joints in the deck at intermediate piers. Intermediate pier to deck connections may be fully continuous or the deck may be supported on bearings.

9.2.2 General requirements

Basis for selection
AS 5100.4 Clause 5 requires that the number of deck joints in a bridge is minimised. The aims of this requirement are to improve ride-quality and to eliminate the need for potentially hazardous and costly inspection and repair of joints over the life of the bridge. Both the integral and the semi-integral forms of construction eliminate the need for movement joints and shall be considered in the first instance for use in all new bridges that meet the requirements of Clause 4 of this document.

The decision to adopt the integral form of construction must be based on a thorough consideration of structural, geotechnical and backfill options.

Advantages
Integral bridges have the following advantages:

- Improved structural reliability and redundancy
- Improved long-term serviceability
- Improved ride-quality and noise reduction
- Potential for reduced initial cost
- Reduced maintenance requirement leading to the elimination of the hazards associated with bearing and joint inspection and their maintenance*
- Reduced traffic disruption derived from elimination of maintenance requirement
- Lower whole-of-life cost and
- Improvement of bridge appearance through elimination of staining caused by water leakage through joints.

Restrictions on use
The integral and semi-integral forms of bridge construction may be used on single and multi-span bridges subject to the restrictions on span, skew and the range of thermal movement at the abutments specified in Clause 9.2.3.

Foundation type
The choice of foundation type for an integral bridge abutment will depend on the ground conditions and considerations of soil-structure interaction. Piled foundations may not be suitable for use in very stiff soils and rocks as these ground conditions restrict flexure in the piles arising from cyclical thermally-induced movements of the superstructure. A framed abutment may be more appropriate in the case of very stiff soils and rocks.

9.2.3 Design limitations and requirements

Maximum overall length
The maximum overall length shall not exceed 70 metres. This limit is aimed at controlling the maximum passive soil pressure arising from thermally-induced cyclical displacements at the abutments which will, in-turn limit the maximum stresses in the piles and, the magnitude of cracks between the approach slab and approach pavement.

Maximum thermal movement
The maximum range of thermally induced cyclic movement at each abutment shall not exceed ±20mm.

Structure geometry
Integral bridge design is permissible for straight and curved-in-plan bridges with a skew not greater than 30°.

Highly skewed and curved bridges may tend to rotate in plan as a result of the action of thermally-induced forces in the superstructure which, in turn, mobilise passive resistance at the abutments in the form of a couple. This may lead to proportional increases in the horizontal loads on piled foundations.

Serviceability limit state
Tensile stresses shall be evaluated at critical locations to ensure that crack-widths remain within specified limits.

Approach slab
The minimum length of approach slab should be one and a half times the depth of the abutment below the soffit of the approach slab measured perpendicular to the fender wall but not less than 4m.

9.2.4 Inspection and maintenance

Choice of details and components must be made with the aim of maximising the life of components to first maintenance and minimising the need for subsequent maintenance operations. Irrespective of the choice of bridge form and details, consideration must be given to accessibility for inspection, maintenance and replacement of bridge components throughout the life of the bridge, particularly where the details include items such as elastomeric bearings, pads and joint-fillers.