BTN 005

January 2018

Code of Practice
FRP for strengthening of bridge structures

1. Scope and application

Bridge Technical Note BTN005 Fibre reinforced polymer (FRP) for strengthening of bridge structures, states VicRoads' requirements for the use of FRP composites for strengthening of bridge structures.

The purpose of this BTN005 is to provide additional requirements and information regarding the use of FRP composites for strengthening of reinforced and prestressed concrete structures.

BTN005 is to be read in conjunction with:

- AS5100.8
- VicRoads Standard Specification 688.

Bridge Technical Notes are a Code of Practice. Compliance with Bridge Technical Notes is mandatory.

Other than as stated in this document and relevant VicRoads Standard Specifications, the provisions of AS5100:2017 shall apply. Where this document differs from AS5100:2017, its requirements override those of AS5100:2017.

2. 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 Level 3 bridge investigation, a review of existing design documents, drawings and a structural analysis. The Level 3 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 as specified in VicRoads Standard Specifications 610 and 688.

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

3. Design requirements

3.1. General

Attention is drawn to the corrections listed in Appendix A.

3.2. 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.

3.3. 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.

3.4. Loading

Design loading for FRP strengthening at the serviceability and ultimate limit states shall be in accordance with the requirements of AS 5100:2017.

3.5. 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 Cl. 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

3.6. 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.

3.7. 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.

4. 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.

5. 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.

6. 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 Superintendent for evaluation and approval.

7. Requirements for design and proof engineering

FRP strengthening shall be designed and proof engineered by Designers and Proof Engineers who are pre-qualified at Structures Complex level and Proof Engineering level respectively in accordance with VicRoads Pre-qualification Scheme.

Alternatively design and proof engineering may be conducted by an experienced person who has specialist knowledge of FRP materials and design methods and who has been approved for this purpose by the Principal Bridge Engineer.

Principal Bridge Engineer
VicRoads

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Bridge Technical Notes are subject to periodic review and may be superseded.

Appendix A

The following errors in AS5100.8 have been identified*:

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

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

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

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.

Designers are required to use the above corrected formulae when preparing designs.

*the errors have been referred to the AS5100 committee for amendment.