

Annexure

S04: Tier 2 Assessments of Shear in Concrete Short Span Bridges

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Amendment Register

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1.02	All	Editorial changes to reflect new corporate editing requirements	DCE (Structures)	August 2013
1.01	Section 2.2.2	Added diagram related to the determination of A_{sv}/S for shear capacity calculations	DCE (Structures)	May 2012
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1 Introduction

1.1 Background

Tier 2 assessments and Level 3 inspections of bridges are invoked when Tier 1 theoretical assessments of bridges determine that a structure is a “Potentially Structurally Deficient Bridge”. Tier 2 assessments form part of a hierarchy of procedures that respond to the competing demands to:

- provide safe access to the road network
- maximise utilisation of the road network to facilitate economic development of the state (this includes limiting delays, reducing congestions, and keeping the road network open)¹.

The Tier 1 shear strength assessment of concrete bridges is presented in *Annexure S03: Tier 1 Assessment of Shear in Reinforced and Prestressed Concrete Short Span Bridges* to AS 5100 and AS 3600.

Tier 2 assessments aim to use state-of-the-art methods such as Modified Compression Field Theory (MCFT) developed in Canada and incorporated in the current Canadian Highway Bridge Design Code (CHBDC) and the American Association of State Highway and Transportation Officials (AASHTO) Load and Resistance Factor Design (LRFD) bridge design specifications. Similarly, the strut-tie provisions of the CHBDC are state-of-the-art provisions that are informed by MCFT.

MCFT is a rational method derived from applying conditions of equilibrium and compatibility of strains, using appropriate stress-strain relationships for reinforcement and diagonally cracked concrete.

Most bridge headstocks, girders and cross-girders are large enough to require shear reinforcement to comply with standards such as AS 5100.5. Unfortunately, a number of Transport and Main Road’s bridges have been identified with substantially less than the minimum shear reinforcement.

Unfortunately there are no specific assessment provisions for shear strength in Australian Standards and no guidance for the scenario where the shear reinforcement provided is less than the minimum permitted by the Standard. The CHBDC provisions for evaluation of shear strength specifically address the shear strength of members with little or no shear reinforcement.

In addition, the CHBDC provisions for the assessment of prestressed concrete girder shear strength are more straightforward to apply compared to AS 5100.5.

For these reasons, the CHBDC methods for assessing the shear strength of concrete structures have been recommended for Tier 2 assessments of short span bridges. The recommendations are presented in the following section.

The CHBDC is calibrated using material resistance factors rather than capacity reduction factors. The material factors associated with concrete, reinforcing steel and prestressing strand vary between 0.75 and 0.95. Thus adopting a capacity reduction approach (i.e. all material factors are the same) is inconsistent with the calibration approach and therefore not recommended. This was confirmed when trials conducted using material factors set to the AS 5100.5 capacity reduction factor generated inconsistent results when compared to AS 5100.5.

¹ refer Transport and Main Road’s “Structural Assessment of Existing Road Bridges Organisational Policy”, 20 Sep 2012

The material factors for Section Assessment are larger than the capacity reduction factor of $\phi = 0.7$ that is applied for shear in AS 5100.5 (refer Table 1). The material factors included in Transport and Main Road's recommendations are consistent with the Canadian Building Code rather than the CHBDC and range between 0.65 (cast-in-situ concrete) and 0.9 (prestressing strand), thus providing a closer relationship to the AS 5100.5 capacity reduction factors. The material factor for concrete is lower for cast-in-situ concrete ($\phi_c = 0.65$) compared to precast concrete ($\phi_c = 0.7$), better reflecting the variability of these two materials, especially in older bridges. These are also consistent with the AS 5100.5 $\phi = 0.7$. The material factors for reinforcing steel ($\phi_s = 0.85$) are higher, reflecting the higher level of confidence associated with steel. AS 5100.5 capacity reduction factor for concrete in bending ($\phi = 0.8$) better reflects the variability of reinforcing steel although there is some concrete variability incorporated. Thus a material factor for reinforcing steel slightly larger than the capacity reduction factor for bending seems reasonable. The recommended material factors appear to be reasonable yet conservative compared to the CHBDC.

1.2 Purpose

The purpose of this annexure is to:

- provide recommendations for the Tier 2 shear strength assessment of existing reinforced and prestressed concrete short span bridges that a Tier 1 assessment has shown to be potentially structurally deficient
- discuss the background to the recommendations.

1.3 Scope

In scope:

- Tier 2 assessment of existing reinforced and prestressed concrete substructures and superstructures in short span bridges.

Out of scope:

- Design of new structures
- Members that require significant reinforcement to resist torsion (i.e. the combined bending shear and torsion effects are critical).

1.4 Related documents

This annexure is to be read in conjunction with *Annexure S03: Tier 1 Assessment of Shear in Reinforced and Prestressed Concrete Short Span Bridges* to AS 5100 and AS 3600.

1.5 Responsibilities of users

This document is to be applied by structural engineers who use their engineering knowledge and experience to assess the strength of structures. Engineering organisations and engineers applying this document are to convey any concerns and/or suggested improvements to the Deputy Chief Engineer (Structures Section), in writing, in a timely manner.

Ultimately it is the responsibility of the engineer to apply reasonable engineering judgement in the assessment of structures to ensure that the results are appropriate for a Tier 2 assessment of the structure.

2 Recommendations for the department's projects

2.1 Introduction

This section sets out the recommendations for the Tier 2 Assessment of reinforced and prestressed concrete shear strength of short span bridges.

2.2 Assessment models

2.2.1 Introduction

When it is reasonable to assume that plane sections remain plane, components shall be assessed for shear using either the sectional assessment model specified in Section 2.2.2 sectional assessment model or the strut-and-tie model specified in Section 2.2.3 strut-and-tie model.

When the plane sections assumption of flexural theory is not applicable, components shall be assessed for shear using the strut-and-tie model specified in Section 2.2.3 strut-and-tie model. The strut-tie model applies to regions near supports and concentrated loads, especially when the distance between the centres of the applied load and the supporting reaction is less than twice the component thickness (depth).

2.2.2 Sectional assessment model

The Tier 2 shear strengths are to be assessed in accordance with the CHBDC Section 14.14.1.6 Shear in concrete beams and referenced clauses, with the following modifications and clarifications:

- Use loads and load factors as specified in the department's Heavy Load Assessment Project Criteria for external consultants.
- The material resistance factors in Table 8.1 of the CHBDC shall be replaced by the material resistance factors in Table 1.

Table 1: Material Resistance Factors to be used in conjunction with the sectional assessment model

	Material	Material resistance factor
Concrete	– cast-in-situ	$\phi_c = 0.65$
	– precast	$\phi_c = 0.70$
	Reinforcing bars, wire, and wire fabric	$\phi_s = 0.85$
	Prestressing strand, and high strength bars	$\phi_p = 0.90$

- Replace Clause 14.14.1.6.1 *General* with:
Concrete beams shall have their shear resistance calculated in accordance with Clause 8.9.3 excluding Clause 8.9.3.6², except as modified in Clauses 14.14.1.6.2 and 14.14.1.6.3.

² i.e. including the Modified Compression Field Theory general method but excluding the MCFT simplified method.

- Some of the differences in nomenclature between AS 5100.5 and the CHBDC are highlighted in Table 2.

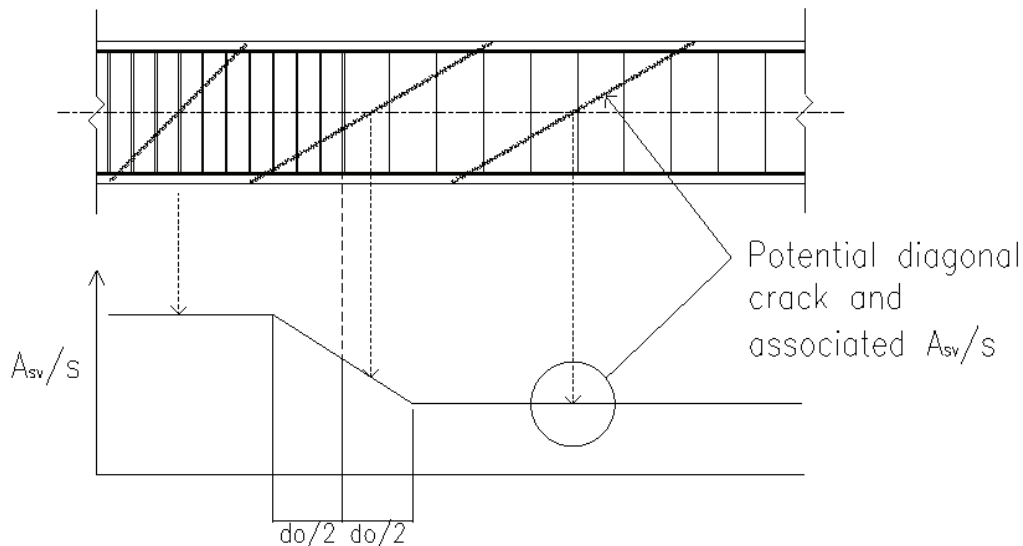
Table 2: Selected equivalences between AS 5100.5 and the CHBDC

AS 5100.5	CHBDC
$V^* \leq \phi V_u = \phi(V_{uc} + V_{us})$	$V_f \leq V_r = V_c + V_s + V_p$
M^*	M_f
N^*	N_f
$\phi V_{uc} = \phi \left(\beta_1 \beta_2 \beta_3 b_v d_o \left[\frac{(A_{st} + A_{pt}) f_c'}{b_v d_o} \right]^{1/3} + V_0 + P_v \right)$	$V_c = 2.5 \beta \phi_c f_{cr} b_v d_v$ $V_p = \phi_p P_v$
$\phi V_{us} = \frac{\phi A_{sv} f_{sy} f d_o}{s} \cot \theta_v$	$V_s = \frac{\phi_s A_v f_y d_v}{s} \cot \theta$

Note: $d_o \neq d_v$

- Note that the reduction in the effective width of webs due to prestressing ducts is less conservative in the CHBDC compared to AS 5100.5.
- The expression in CHBDC Clause 8.9.3.3 shall be replaced by³:
 $V_c + V_s \leq 0.22 \phi_c f_c' b_v d_v$
- CI 14.14.1.6.3.2 provides a method for calculating $A_v h/s$ by averaging over a length h . This provision does not preclude the application of $\cot \theta$ in the CHBDC CI 8.9.3.5 (a). For further related information, refer *Annexure S03* and Figure 1.

Figure 1: Determination of A_{sv}/s for shear capacity calculations



³ The constant has been adjusted so that the $V_c + V_s \approx \phi V_{u,max}$ for cast-in-situ concrete.

2.2.3 Strut-and-tie model

The Tier 2 shear strengths are to be assessed in accordance with the CHBDC Section 8.10 strut-and-tie model and referenced clauses, with the following modifications and clarifications:

- Use loads and load factors as specified in the department's Heavy Load Assessment Project Criteria for external consultants.
- Exclude Clause 8.10.6 crack control reinforcement unless there is significant redistribution of internal stresses between the serviceability limit state and the ultimate limit state corresponding to the strut-tie model.
- Use strength reduction factors as specified in AS 3600-2009 for design using strut-and-tie analysis (refer AS 3600-2009 Table 2.2.4) as summarised in Table 3.

Table 3: Material Resistance Factors to be used in conjunction with the strut-and-tie model

Material	Material resistance factor
Concrete	$\phi_c = 0.6$
Reinforcing bars, wire, and wire fabric	$\phi_s = 0.8$
Prestressing strand, and high strength bars	$\phi_p = 0.8$

3 Bibliography

Canadian Standards Association, 2004, CAN/CSA-S6-00, Canadian Highway Bridge Design Code, Toronto, Ontario

Standards Australia, 2009, "AS 3600–2009 Concrete Structures"

Standards Australia, 2004, "AS 5100.5–2004 Bridge Design Part 5: Concrete"

Standards Australia, 2008, "AS 5100.5 Supp 1-2008 Bridge Design–Concrete–Commentary (Supplement to AS 5100.5–2004)"

