C10. Longitudinal Shear Reinforcement Design

C10.1 Introduction

This section is concerned with the design of reinforcement in the vicinity of the shear studs that is necessary to control potential longitudinal shear failure adjacent these studs. It could be regarded as being part of the slab design or the beam design or even could be considered as part of connection design.

The phenomenon of longitudinal shear failure in composite slabs is likely to be relatively foreign to engineers who have not previously worked with composite structures. The simplest form of longitudinal shear failure is illustrated below. Note that this shows a “trapezoidal” deck that is specifically excluded from the applicability of AS2327.1. It is shown here because it is easier to visualise longitudinal shear issues using this decking form.

The ‘potential’ concrete flange to the steel beam - provided that the force $F_c$ can be carried into it by the shear stress spreading out from the shear stud.

The shape of the profiled decking gives rise to longitudinal planes of weakness where the shear stress carrying the compression to the width of the flange becomes concentrated. A shear plane of this sort is defined in AS2327.1 Figure 9.4.1 as being a “Type 1” shear plane. This form of failure is most likely to be critical for a primary beam as shown above. For secondary beams with the ribs perpendicular to the beam there is no plane of weakness but the same form of failure may still develop through the full depth of the slab. As this form of failure goes right through the depth of the slab then it will be controlled by both top and bottom reo (if present) running perpendicular to the beam and thus passing across the shear plane.

Shown below are Type 2 and Type 3 shear planes to AS2327.1. Note that these failure planes run below the level of the top reo. They will only be controlled by bottom reinforcement (if present). These forms of shear failure may again affect both primary and secondary beams but are most likely to be critical for primary beams with the ribs running parallel to the beams.
The most difficult to visualise form of longitudinal shear failure is called a Type 4 shear failure. Refer to AS2327.1 Figure 9.4.1 for an illustration of this form of failure. A type 4 shear failure will only affect an edge beam where the ribs are perpendicular to the beam.

A type 4 shear plane effectively initiates at the free edge of the slab just above the ribs and extends inwards. When it reaches the shear studs the shear plane deviates upwards to pass over the top of the shear studs and then returns to the level of the top of the ribs. The first “line of defence” against this form of failure is the requirement of AS2327.1 Figure 3.1.4 that the slab outstand must extend 150 beyond the face of the nearest shear stud. For the current design this distance is 200.

The difficulty with a type 4 failure plane is that it manages to avoid both the top and bottom reo. Neither top nor bottom reo will cross the shear plane and thus will not control this type 4 failure. A special form of mesh called “Deckmesh” has been developed specifically to control this form of failure as discussed in the next section. Generally Deckmesh or equivalent should be used at slab edges for all edge beams where the ribs are perpendicular to the beam such as beams B19, 20, 21 and B49, 50 and 51.

AS2327.1 does not provide a design method to assess the Type 4 failure but rather provides a prescriptive definition of the requirements for all edge beams with perpendicular ribs.

The capacity of a composite slab to resist Type 1, Type 2 and Type 3 longitudinal shear failure is assessed using the so called “shear friction” method with the shear capacity given as:

\[ \phi V_L = \phi[u(0.36f'_c^{0.5}) + 0.9A_{sv}f_y] \]

But not greater than \( \phi 0.32f'_c u \)

With
- \( u \) = the perimeter of the shear plane as viewed in cross section through the beam
- \( A_{sv} \) = the area of reinforcement that passes from one side of the shear plane to the other
- \( f_y \) = the yield strength of the reinforcement \( A_{sv} \)

In the equation for \( \phi V_L \), the first term may be thought of as the “cohesion” or “chemical” component and relates to the tensile strength of the concrete. The second term in the equation is the “friction” component with a coefficient of friction of 0.9 across the failure plane. The logic is that in order for longitudinal slip to develop at the shear plane, it will be necessary to pull the concrete apart across the shear plane to disengage aggregate interlock. In order to pull the two planes apart, it will be necessary to apply a force equal to the tensile capacity of the reinforcement that crosses the plane. That is the friction resistance assessed using the normal “law of dry friction” is \( \mu N \) where the coefficient of friction \( \mu = 0.9 \) and the normal force \( N = A_{sv}f_y \).

In accordance with AS2327.1 the following represents basic requirements for longitudinal shear reinforcement.

- In accordance with AS2327.1 Clause 9.7.2, all beams require longitudinal shear reinforcement with a minimum cross sectional area of 0.5 x 800 x \( u / f_y \) mm\(^2\) / m (refer later examples). This reinforcement is to be placed directly on top of the decking ribs. The minimum width of this reinforcement is to satisfy the requirements of Clause 9.7.3.

- In accordance with AS2327.1 Clause 9.8.1, all edge beams with the sheeting perpendicular to the beam require “special” longitudinal shear reinforcement complying with the requirements of Clause 9.8.2. (There is a possible exception where the slab outstand is greater than 600.)

- All beams must be checked for longitudinal shear reinforcement requirements for Type 1 shear planes. As a Type 1 shear plane extends from top to bottom of slab, both top and bottom reinforcement will reinforce against a Type 1 shear failure.

- All beams must be checked for longitudinal shear reinforcement requirements for Type 2 shear planes. As a Type 2 shear plane does not extend to the top of the slab, only bottom reinforcement placed a minimum of 30 mm below the top of the shear studs is considered to resist against a Type 2 shear failure.
Beams with the decking ribs parallel to the beam must be checked for longitudinal shear reinforcement requirements for Type 3 shear planes. As a Type 3 shear plane does not extend to the top of the slab, only bottom reinforcement placed a minimum of 30 mm below the top of the shear studs is considered to resist against a Type 2 shear failure.

C10.2 Proprietary longitudinal shear reinforcement products

To suit the particular requirements of reinforcement for longitudinal shear, various reinforcement products have been developed. One set of such products is offered by Onesteel. Refer to the Onesteel website (http://www.onesteel.com) and navigate through Product navigation / Onesteel products / Reinforcing steels / Other mesh / Deck mesh .... And download the “Shear reinforcement brochure”. The products relevant to the use of Bondek are “Studmesh” and “Deckmesh”.

Deckmesh is intended to satisfy the requirements of AS2327.1 for Type 4 longitudinal shear failure. It is also referred to as “waveform” because of its particular form that is required to intersect the Type 4 shear planes. Onesteel offers two weights of Deckmesh called DM200 and DM300. At the time of developing this text, Onesteel were recommending the use of Deckmesh DM200 for use in Bondek slabs. As previously discussed Deckmesh (or equivalent) is required for all edge beams where the ribs run perpendicular to the beam.

Studmesh is a simple flat rectangular mesh rather similar to “trenchmesh” but with the larger diameter wires running across the width of the mesh. Studmesh is intended to be laid directly on top of the decking ribs to provide bottom reinforcement to reinforce across the Type 2 and Type 3 shear planes. Studmesh together with the top reinforcement will also reinforce against Type 1 failures. Studmesh comes in two forms. Studmesh “SMS” is intended for internal beams and is 600 wide providing for anchorage on either side of the beam. “SMU” is intended for edge beams. It is 500 wide with the main cross wires formed into a U shape to achieve anchorage for edge beams that are closer than 300 to an edge. Studmesh comes in a range of weights to suit the calculated reinforcement requirements for Type 1, 2 and 3 shear planes.

All studmesh products consist of 10 mm Grade 500 main cross wires at variable centres and 6 mm longitudinal (distribution) wires at 300 centres. The nomenclature is for example “SMS100” referring to Studmesh with the main 10 mm wires at 100 centres. The Studmesh “U” mesh is provided in a more limited range of sizes. In the following table $A_{sp,b}$ is the cross sectional area of the main wires at right angles to the beam in mm$^2$/m.

<table>
<thead>
<tr>
<th>SMS</th>
<th>100</th>
<th>150</th>
<th>200</th>
<th>250</th>
<th>300</th>
<th>350</th>
<th>400</th>
<th>450</th>
<th>500</th>
<th>550</th>
<th>600</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_{sp,b}$</td>
<td>800</td>
<td>533</td>
<td>400</td>
<td>320</td>
<td>266</td>
<td>228</td>
<td>200</td>
<td>177</td>
<td>160</td>
<td>143</td>
<td>133</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SMU</th>
<th>200</th>
<th>300</th>
<th>400</th>
<th>500</th>
<th>600</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_{sp,b}$</td>
<td>800</td>
<td>533</td>
<td>400</td>
<td>320</td>
<td>266</td>
</tr>
</tbody>
</table>

In addition to providing a sufficient area of reinforcement, AS2327.1 Clause 9.7.1 also requires that the main transverse wires should be located not more than $s_e / 2$ from each stud (where $s$ is the stud spacing). This will generally mean that a minimum of SMS400 should be used for beams with studs at 400 centres and SMS200 for beams with studs at 200 centres (or SMU400 and SMU200 for edge beams).
C10.3 Secondary beams group S1, B22 typical – longitudinal shear design

Application of Clause 9.7.2 of AS2327.1

Minimum bottom reinforcement:

$$A_{sp.b} = 0.5 \times 800 \times u / f_{yr} \text{ mm}^2 / \text{m}$$

With only a single stud at each cross section, the shear perimeter of the type 2 shear plane with 19 mm studs 90 mm high will be:

$$u = 2 \times 90 + \text{head diameter} = 200 \text{ (say)}$$

Thus

$$A_{sp.b} = 0.5 \times 800 \times u / f_{yr}$$
$$= 0.5 \times 800 \times 200 / 500$$
$$= 160 \text{ mm}^2 / \text{m}$$

TRY SMS400 with $$A_{sp.b} = 200 \text{ mm}^2 / \text{m}$$ placed directly on top of the ribs and central over all secondary beams. (SMS500 provides a sufficient area of reinforcement but does not satisfy the detailing requirements of AS2327.1 Clause 9.7.1.)

Application of Clause 9.3.2 of AS2327.1

With

$$n_{i,max} = 14$$
$$f_{ds} = \phi_k f_{ys} = 0.85 \times 1.13 \times 89 = 86.2 \text{ kN}$$
$$V_{L,tot}^* = n_i f_{ds} / s_c = 1 \times 86.2 / 0.4 = 216 \text{ kN (per metre length of beam)}$$

Consider a Type 1 shear plane

$$V_{L}^* = \left( x / b_d \right) V_{L,tot}^*$$
$$= 216 / 2 = 108 \text{ kN / m}$$
Composite Design Example for Multistorey Steel Framed Buildings

Copyright © 2007 by AUSTRALIAN STEEL INSTITUTE

Published by: AUSTRALIAN STEEL INSTITUTE

All rights reserved. This book or any part thereof must not be reproduced in any form without the written permission of Australian Steel Institute.

Note to commercial software developers: Copyright of the information contained within this publication is held by Australian Steel Institute (ASI). Written permission must be obtained from ASI for the use of any information contained herein which is subsequently used in any commercially available software package.

FIRST EDITION 2007 (LIMIT STATES)

National Library of Australia Cataloguing-in-Publication entry:
Durack, J.A. (Connell Wagner)
Kilmister, M. (Connell Wagner)
Composite Design Example for Multistorey Steel Framed Buildings
1st ed.
Bibliography.
ISBN 978-1-921476-02-0

1. Steel, Structural—Standards - Australia.
2. Steel, Structural—Specifications - Australia.
   I. Connell Wagner
   II. Australian Steel Institute.
   III. Title

Disclaimer: The information presented by the Australian Steel Institute in this publication has been prepared for general information only and does not in any way constitute recommendations or professional advice. The design examples contained in this publication have been developed for educational purposes and designed to demonstrate concepts. These materials may therefore rely on unstated assumptions or omit or simplify information. While every effort has been made and all reasonable care taken to ensure the accuracy of the information contained in this publication, this information should not be used or relied upon for any specific application without investigation and verification as to its accuracy, suitability and applicability by a competent professional person in this regard. Any reference to a proprietary product is not intended to suggest it is more or less superior to any other product but is used for demonstration purposes only. The Australian Steel Institute, its officers and employees and the authors, contributors and editors of this publication do not give any warranties or make any representations in relation to the information provided herein and to the extent permitted by law (a) will not be held liable or responsible in any way; and (b) expressly disclaim any liability or responsibility whatsoever for any loss or damage costs or expenses incurred in connection with this publication by any person, whether that person is the purchaser of this publication or not. Without limitation, this includes loss, damage, costs and expenses incurred as a result of the negligence of the authors, contributors, editors or publishers.

The information in this publication should not be relied upon as a substitute for independent due diligence, professional or legal advice and in this regards the services of a competent professional person or persons should be sought.
# Table of contents

*Preface* ........................................................................................................................................................................... iii

**Section A: INPUT INFORMATION** ........................................................................................................................................ 1
A1. Client and Architectural Requirements .................................................................................................................. 2
A2. Site Characteristics ..................................................................................................................................................... 4
A3. Statutory Requirements ............................................................................................................................................... 5
A4. Serviceability ............................................................................................................................................................ 8
A5. Design Loads ........................................................................................................................................................... 9
A6. Materials and Systems .............................................................................................................................................. 10
A7. Design Aids and Codes ........................................................................................................................................... 11

**Section B: CONCEPTUAL AND PRELIMINARY DESIGN** ................................................................................................. 12
B1. Conceptual and Preliminary Design .......................................................................................................................... 13
   B1.1 Consideration of alternative floor framing systems– Scheme A .................................................................................... 14
   B1.2 Consideration of alternative floor framing systems– Scheme B .................................................................................... 15
   B1.3 Framing system for horizontal loading – initial distribution of load ........................................................................ 16
   B1.4 Alternatives for overall distribution of horizontal load to ground ........................................................................ 17
B2. Preliminary Slab Design ............................................................................................................................................... 21
B3. From Alternatives to Adopted Systems .................................................................................................................. 22
   B3.1 Adopted floor framing arrangement ...................................................................................................................... 22
   B3.2 Adopted framing arrangement for horizontal loading ............................................................................................ 23
B4. Indicative Construction Sequence and Stages ........................................................................................................ 24
   B4.1 The importance of construction stages in composite design .................................................................................. 24
   B4.2 Indicative construction sequence and construction stages ................................................................................... 25
   B4.3 Core construction alternatives .................................................................................................................................. 27
   B4.4 Adopted construction method for the core ............................................................................................................. 27
B5. Preliminary Sizing of Primary and Secondary Beams ............................................................................................. 28
B6. Plenum Requirements and Floor to Floor Height ..................................................................................................... 30
B7. Preliminary Column Sizes and Core Wall Thickness ............................................................................................... 33

**Section C: DETAILED DESIGN** ...................................................................................................................................... 35
C1. Detailed Design - Introduction ................................................................................................................................... 36
C2. Design Stages and Construction Loading ................................................................................................................ 37
C3. Detailed Load Estimation After Completion of Construction .................................................................................... 38
   C3.1 Vertical loading ..................................................................................................................................................... 38
   C3.2 Wind loading ....................................................................................................................................................... 39
   C3.3 Seismic loading: Not considered .......................................................................................................................... 40
C4. Erection Column Design ............................................................................................................................................ 41
   C4.1 Load distribution for erection column design ...................................................................................................... 42
   C4.2 Side Column C5 (typical of C5 to C10) ................................................................................................................ 43
   C4.3 End column C2 (typical of C2, C3, C12 and C13) .................................................................................................... 44
   C4.4 Corner column C1 (typical of columns C1, C4, C11 and C14) ............................................................................. 44
C5. Floor Beams – Construction Stage 1 ........................................................................................................................ 45
   C5.1 Secondary beams Group S1(11 050, 2800) (Beams B22 – B41, B43 – 48) ................................................................. 45
   C5.2 Primary beams Group P1(9800, 5725) (Beams B1, B7 to B12, B18, B19 – 21, B49 – 51 and B42) ...................... 46
   C5.3 Primary beams Group P2(9250, 6600) (B2, B6, B13 and B17) ................................................................................. 47
C6. Floor Beams – Construction Stage 3 ........................................................................................................................ 48
   C6.1 Secondary beams Group S1(11 050, 2800) (Beams B22 – 41, B43 – 48) ................................................................. 48
   C6.2 Primary beams Group P1(9800, 5725) (Beams B1, B7 – B12, B18 – 21, B49 – 51 and B42) ................................. 49
   C6.3 Primary beams Group P2(9250, 6600) (Beams B2, B6, B13, B17) ........................................................................... 49
C7 Floor Beam Design for Occupancy Loading .............................................................................................................. 50
   C7.1 Secondary beams Group S1(11 050, 2800) (Beams B19, B21, B22 - B41, B43 – B49 and B51) ..................... 51
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>C7.2 Primary beams Group P1(9800,5725) (Beams B1, B7 to B12, B18)</td>
<td>58</td>
</tr>
<tr>
<td>C7.3 Primary beams group P2(9050, 6600) (Beams B2, B6, B13, B17)</td>
<td>63</td>
</tr>
<tr>
<td>C8. Assessment of Dynamic Performance of Floor System</td>
<td>69</td>
</tr>
<tr>
<td>C8.1 Definition of the dynamic assessment process</td>
<td>69</td>
</tr>
<tr>
<td>C8.2 Application of the dynamic assessment process</td>
<td>73</td>
</tr>
<tr>
<td>C9 Final Slab Design</td>
<td>79</td>
</tr>
<tr>
<td>C9.1 Slab design for the office areas</td>
<td>79</td>
</tr>
<tr>
<td>C9.2 Slab design for the compactus areas</td>
<td>80</td>
</tr>
<tr>
<td>C10. Longitudinal Shear Reinforcement Design</td>
<td>81</td>
</tr>
<tr>
<td>C10.1 Introduction</td>
<td>81</td>
</tr>
<tr>
<td>C10.2 Proprietary longitudinal shear reinforcement products</td>
<td>83</td>
</tr>
<tr>
<td>C10.3 Secondary beams group S1, B22 typical – longitudinal shear design</td>
<td>84</td>
</tr>
<tr>
<td>C10.4 Internal primary beams group P2, ( B2 typical) longitudinal shear design</td>
<td>85</td>
</tr>
<tr>
<td>C10.5 Primary beams P1, (B1 typical) – longitudinal shear design</td>
<td>87</td>
</tr>
<tr>
<td>C10.6 Perimeter beams B19 to 21 and B49 to 51</td>
<td>88</td>
</tr>
<tr>
<td>C11. Floor System Design Review and Final Decisions</td>
<td>89</td>
</tr>
<tr>
<td>C11.1 Floor design review</td>
<td>89</td>
</tr>
<tr>
<td>C11.2 Final floor framing plan and deck reinforcement</td>
<td>90</td>
</tr>
<tr>
<td>C12. Final Design of RC Columns</td>
<td>91</td>
</tr>
<tr>
<td>C13. Detailed Design of the Core</td>
<td>91</td>
</tr>
<tr>
<td>C13.1 Preliminary discussion and statement of limitations of this section</td>
<td>91</td>
</tr>
<tr>
<td>C13.2 Basic modelling of the core using beam elements</td>
<td>92</td>
</tr>
<tr>
<td>C13.3 The Space Gass Analysis Model</td>
<td>96</td>
</tr>
<tr>
<td>C13.4 Model verification and static deflections for Ws</td>
<td>97</td>
</tr>
<tr>
<td>C13.5 Dynamic analysis for natural frequency of building</td>
<td>98</td>
</tr>
<tr>
<td>C13.6 Interpretation and application of stress resultants from Space Gass</td>
<td>100</td>
</tr>
<tr>
<td>C13.7 Further investigation of the core using a Strand7 finite element model</td>
<td>102</td>
</tr>
<tr>
<td>C13.8 Review of core investigations</td>
<td>105</td>
</tr>
<tr>
<td>C14. Steel Connection Design</td>
<td>106</td>
</tr>
<tr>
<td>C14.1 Can it be built?</td>
<td>106</td>
</tr>
<tr>
<td>C14.2 Representative connections</td>
<td>108</td>
</tr>
<tr>
<td>C14.3 Web side plate connection design for V* = 142 kN</td>
<td>108</td>
</tr>
<tr>
<td>C14.4 Flexible end plate connection for V* = 279 kN</td>
<td>112</td>
</tr>
<tr>
<td>C14.5 B2 to core web side plate connection for V* = 308 kN</td>
<td>113</td>
</tr>
<tr>
<td>C14.6 Column splice for a load of N* = 1770 kN</td>
<td>114</td>
</tr>
<tr>
<td>C14.7 Column base plate for a load of N* = 1770 kN</td>
<td>115</td>
</tr>
<tr>
<td>C15. Web Penetrations</td>
<td>116</td>
</tr>
<tr>
<td>C16. Some Final Thoughts and Disclaimers</td>
<td>117</td>
</tr>
<tr>
<td>Appendix I Theory and discussion – composite slabs</td>
<td>119</td>
</tr>
<tr>
<td>Appendix II Theory and discussion - composite beams</td>
<td>133</td>
</tr>
<tr>
<td>Appendix III Dynamic assessment of the floor system</td>
<td>149</td>
</tr>
<tr>
<td>Appendix IV Theory and discussion steel connections</td>
<td>163</td>
</tr>
<tr>
<td>Appendix V Corrosion and fire protection</td>
<td>175</td>
</tr>
</tbody>
</table>