TECHNICAL NOTE 8

November 2022

Steel Reinforcement Institute of Australia

STRUCTURAL INTEGRITY REINFORCEMENT FOR SLABS

In 2018, based on the lessons learnt from the Christchurch, New Zealand earthquake events in 2011, AS 3600[1] was revised to incorporate many new provisions to safeguard future Australian buildings from seismic events and provide important life safety to the occupants if the buildings are subjected to one of these extreme events.

One simple reinforcement detailing requirement that was incorporated into the Standard was structural integrity reinforcement for both beams and slabs. This nominal amount of reinforcement was found to be very effective at preventing the collapse of slabs following punching shear failures in Christchurch, improving the life safety of the building **Figure 1**. The Newcastle Workers Club is an example of punching shear failure where no structural integrity reinforcement was provided **Figure 2**. The benefits provided by structural integrity reinforcement led the SRIA to include this aspect of detailing on the cover of the 2016 *Guide to Seismic Design and Detailing of Reinforced Concrete Buildings in Australia*, which is also available for free as a pdf copy from the SRIA website. While the Guide includes structural integrity reinforcement, it has come to the attention of the SRIA that the provisions for slabs that were included as Clause 9.2.2 of AS 3600 in 2018, are being misinterpreted. This Technical Note is intended to clarify the intent and requirements of AS 3600 for structural integrity reinforcement for slabs.

Figure 1 Punching shear failure with structural integrity reinforcement preventing collapse of slab, Hotel Grand Chancellor, Christchurch

(*photograph courtesy Peter McBean*)

Figure 2 Punching shear failure at Newcastle Workers Club during the 1989 Newcastle earthquake – no structural integrity reinforcement to reduce the risk of collapse

(*photo courtesy Cultural Collections, the University of Newcastle, Australia*)

What is Structural Integrity Reinforcement

Structural integrity reinforcement is nothing more than a few reinforcing bars passing through the confined core of the column, which is the section within the column reinforcement cage **Figure 3**. This is critical, as research and evidence from past earthquakes has shown that the unrestrained cover concrete can be lost as a result of the lateral displacement of the structure or building during an earthquake **Figure 4**.

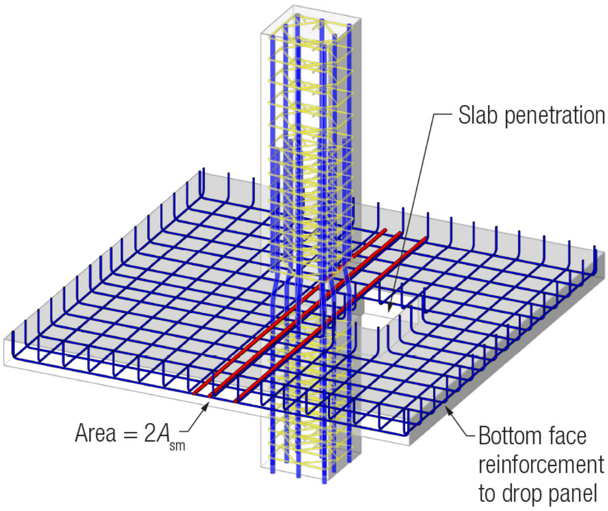


Figure 3 3D view of reinforcement at column-slab intersection showing structural integrity reinforcement in red

(*detail courtesy of Wallbridge & Gilbert*)

Figure 4 Unrestrained cover concrete to column of Copthorne Hotel in Christchurch lost during 2011 seismic event

(*photograph courtesy Peter McBean*)

AS 3600 Provisions for Slabs

These are covered in Clause 9.2.2 of AS 3600 (2018). Paragraph 1 states that:

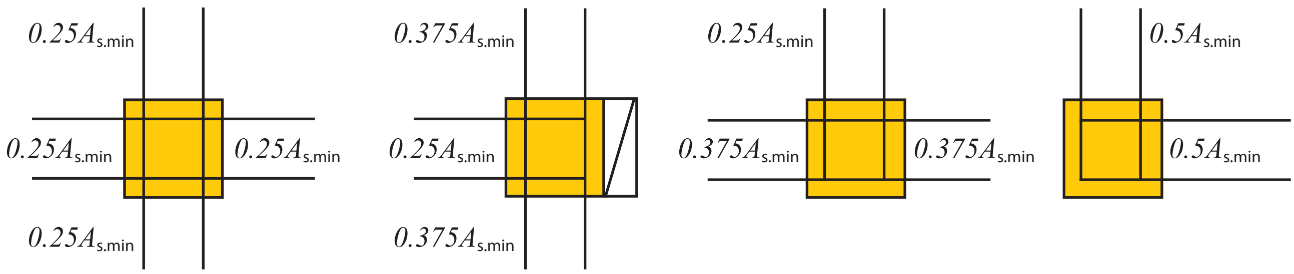
"*The summation of the area of bottom reinforcement connecting the slab, drop panel, or slab band to the column or column capital on all faces of the periphery of a column or column capital shall be not less than,*

$$A_{s.min} = \frac{2N^*}{\phi f_{sy}}$$ *Equation 9.2.2*

in which N is the column reaction from the floor slab at the ultimate limit state.*"

Referring to Figure C9.2.2(A) of the AS 3600 Commentary (2022)², Equation 9.2.2 assumes bars bend to 30° to the horizontal and the vertical component of the tension force at the bar's yield strength supports the slab reaction. This model is consistent with many universally accepted text books.

The area of reinforcement required by Equation 9.2.2 of AS 3600 should be distributed evenly on all faces of the column **Figure 5**. Note that it must be placed in the bottom and applies to all slabs, included flat plates, flat slabs with drop panels and band beam and slab connections, otherwise it will not be effective in providing membrane action to reduce the risk of collapse. Clause C9.2.2 of the AS 3600 Commentary provides the background to these requirements. Referring to **Figure 2**, it can be seen that the top cover was lost and the top reinforcement which was left exposed, was not effective at preventing collapse. The only reliable way to prevent collapse once you have a full thickness punching shear failure is having fully developed, ductile, bottom face reinforcement connecting the column core to the slab.



(a) Interior column (b) Penetration or edge column (c) Corner column

Figure 5 Example of the arrangement of reinforcement – total area = $A_{s.min}$

The structural integrity reinforcing bars are either spliced with existing bottom reinforcement in the slab in accordance with Clause 13.2 or AS 3600, or are provided as separate bars, extending a distance of $2L_{sy.tb}$ past the face of the column or column capital. They should have hooked or cogged ends at discontinuous edges, including penetrations.

Note that the first paragraph of Clause 9.2.2 of AS 3600 specifically includes the connection of a slab band to a column, as slab bands are still subject to failures due to punching shear. Often, some nominal reinforcement is provided to slab bands within post-tensioned slabs (refer example in **Figure 6**), but slab bands cannot be considered as beams and the nominal reinforcement provided taken as satisfying structural integrity requirements based on the exemption given in Paragraph 2 of Clause 9.2.2 of AS 3600 which states that: "*Integrity reinforcement shall not be required if there are beams containing shear reinforcement and with at least two bottom bars continuous through the joint in all spans framing into the column.*" The reference to beams is intended to refer to members designed in accordance with Section 8 of AS 3600, for which separate structural integrity reinforcement requirements apply.

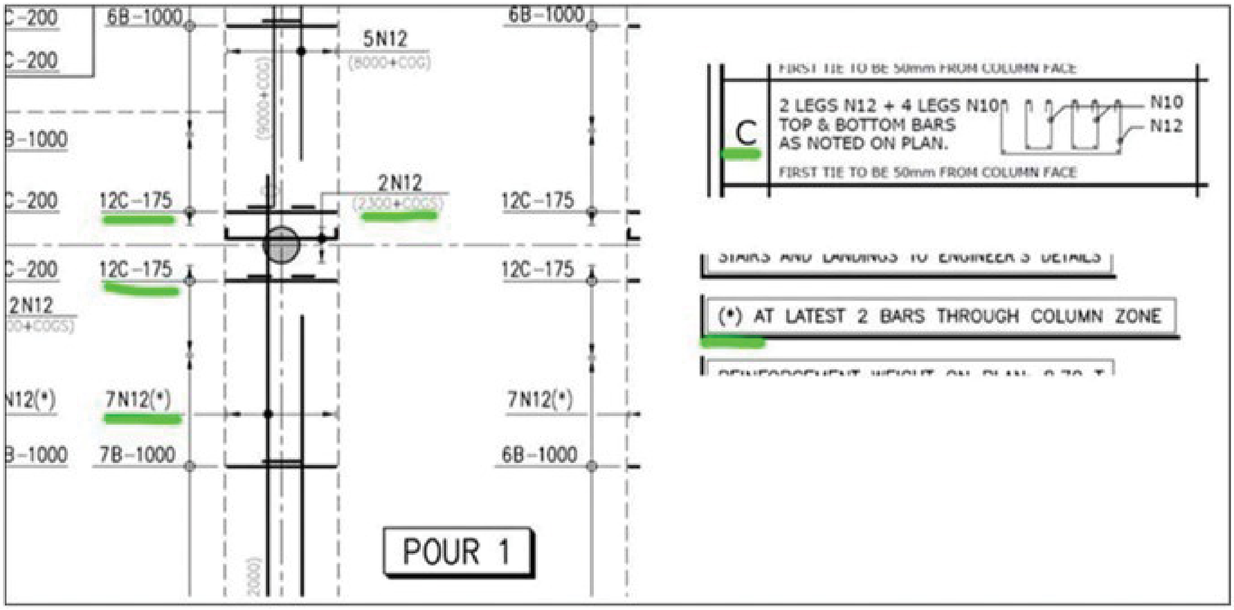


Figure 6 Example of nominal reinforcement to a slab band of a post-tensioned slab (*from SRIA Technical Enquiry*)

The difficulty in assuming that a slab band is a beam, is that slabs, regardless of the presence of a wide band which can be likened to a drop panel in terms of increasing the shear capacity by providing a greater depth of slab at the column location, is that slabs are subject to two-way shear (or punching shear), which is quite different to beam shear. Despite the fact that there are multiple fitment legs detailed across the width of the band beam in **Figure 6**, the shear capacity should still be checked at the critical perimeter which is a distance of $d_{om}/2$ from the face of the column, essentially meaning that the majority of the 'shear' reinforcement in a wide band beam cannot be taken into account for this check. The preferred arrangement of shear reinforcement in a two-way slab (or slab band) is shown in **Figure 7** from the ACI 318M-19 Standard[3], which also shows the critical sections for slab shear that should be checked. Clause 9.3.6 of AS 3600 also requires reinforcement for slab shear to be in the form of closed fitments, with Figure 9.3.6 of AS 3600 providing details of shear reinforcement for slabs.

Structural integrity reinforcement in beams should also be provided with closed fitments, not the undesirable open fitments detailed in the **Figure 6** example (ie 'U' bars anchored with a 180^{o} hook at the top), as the fitments provide no restraint to the compression side of the 'beam'. More information in this regard can be found in SRIA Technical Note 9 and Clause C9.2 of the AS 3600 Commentary.

As punching shear failure is sudden and cannot typically be restrained by taking into account the contribution from the main reinforcement in slabs, in the example shown in **Figure 6**, the minimum area of structural integrity reinforcement required in accordance with Equation 9.2.2 of AS 3600, $A_{s.min.}$, should have been provided as bottom reinforcement over the column and distributed evenly on all faces of the column. Note that the area of the 2N12 bars in **Figure 6** can be taken as part of the minimum area of structural integrity reinforcement required.

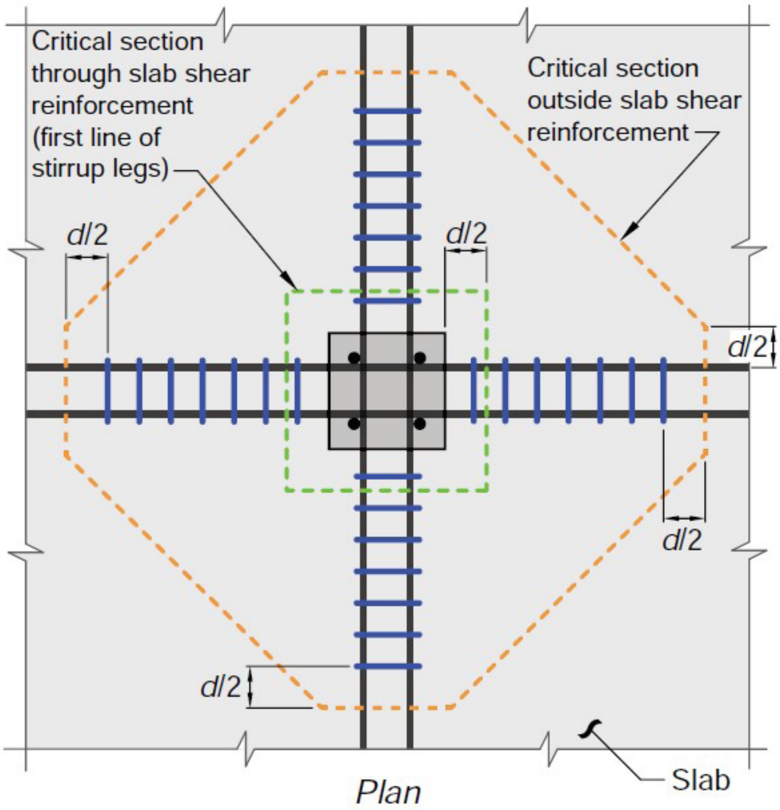


Figure 7 Critical sections for two-way shear in slab with shear reinforcement at interior column (Figure R22.6.4.2a from ACI 318M-19[3])

Where slabs are supported by beams, the structural integrity requirements for these are covered in Section 8 of AS 3600. While AS 3600 does not define what a beam is, the rule of thumb is that the depth is 1.5 to 2 times the width. Slab bands should not be classified as beams, or wide beams, to avoid the provision of the required area of structural integrity reinforcement, $A_{s.min.}$.

Another issue that we come across is whether bonded slab post-tensioning systems can be considered as structural integrity reinforcement. Referring to **Figure 8**, there is no structural integrity reinforcement in the bottom of the slab band over the column. Note that the area of the post-tensioning tendons cannot be taken as part of the required structural integrity reinforcement as ducts are typically located in the top of the slab and/or slab band at column locations. Even if tendons were located over the column itself, C9.2.2 of the AS 3600 Commentary states that, "*Post-tensioning tendons within the column head in the top surface which would normally be considered to contribute to robustness based on a catenary model are not considered to contribute to the post punching shear failure capacity.*" This is because bonded tendons would be the first steel to fracture and thus provide no contribution to structural integrity reinforcement. The collapse of the post-tensioned carpark slabs shown in **Figure 9** demonstrates the importance of providing the required structural integrity reinforcement.

Figure 8 Post-tensioned slab band

(*from SRIA technical enquiry*)

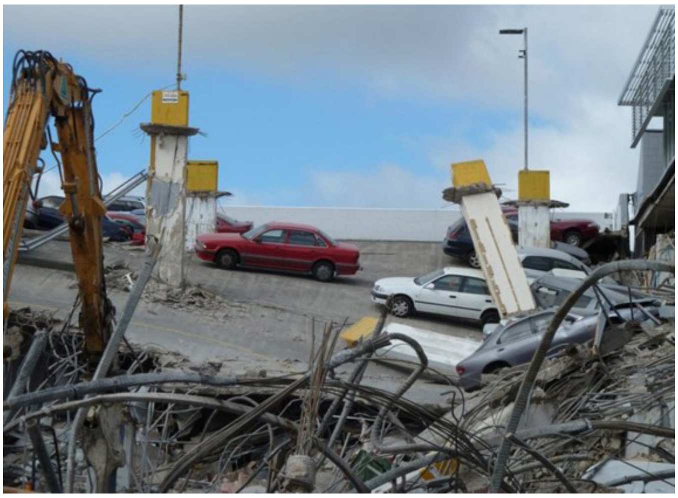


Figure 9 Remains of post-tensioned carpark floor at Christchurch, New Zealand showing punching shear failure at columns

(*photograph courtesy Peter McBean*)

To provide the necessary robustness to buildings and structures to enable them to survive extreme events such as earthquakes, it is essential that the required structural integrity reinforcement for slabs, including flat plates, flat slabs with drop panels, and band beam and slab connections, is provided in accordance with the provisions in AS 3600. It must be located in the bottom of the slab and comply with the detailing requirements provided in Clause 9.2.2 of AS 3600.

References

1. Australian Standards, AS 3600 *Concrete structures*, 2018.
2. Australian Standard AS 3600:2018 Sup 1:2022, Concrete structures – Commentary (Supplement 1 to AS 3600:2018).
3. American Concrete Institute, *Building Code Requirements for Structural Concrete* (ACI 318-11) *and Commentary on Building Code Requirements for Structural Concrete* (ACI 318R-11), 2011.