Technical Assessment - Reinforced Masonry (Besser Block) Steel Reinforcement Requirements for Structural Walls in accordance with AS3700:2018 and AS3600:2018

Abstract

The latest changes to AS3600 and AS1170.4 collectively requires the provision of steel reinforcement to each face for structural walls. This document explains why it is not possible for 190mm thick reinforced masonry walls to comply with this requirement.

The following document has been prepared to inform fellow engineers of the relevance and importance of recent design code changes. As part of the design service, engineers typically provide certification stating that their design is in compliance with the relevant Australian Standards such as AS3600:2018 and AS3700:2018.

When designing a building, the minimum ductility requirements of loadbearing walls under lateral loads (seismic or wind loadings) must be considered. The earthquake does not distinguish between reinforced masonry and concrete walls (in-situ, precast-single or double skin). This is why AS3700:2018 (masonry design code) Clauses 5.9.1, 8.3 and 8.4.4.1 now requires the detailing of reinforcement to be in accordance with AS3600:2018 (concrete design code), modified to suit the particular characteristics of reinforced masonry or unless noted otherwise. Reinforced masonry is not comprised of any material which would allow the wall to perform better than conventional concrete in an earthquake (the same concrete/grout is used as the infill and in addition the masonry shells are brittle) and both walling types are subject to the same cyclic loading.

It is particularly common in some parts of Australia for multi-level buildings to incorporate reinforced masonry as structural walls, such as for dividing sole occupancy units (party walls) and even core/shear walls (lift and stair walls). **AS3700 and AS3600 was revised in 2018 and have now introduced additional requirements for any structure to be designed for earthquake exposure.**

Design Changes

In an earthquake, each floor level within a structure will be subject to inter-storey drift. The magnitude of sway for each floor is greater as the height of the structure increases. As all vertical load bearing elements are tied into the floor levels at both ends, these elements must move in association with the slab and as such the wall displacement at the top of the wall is different to the bottom which introduces localised shear forces within the height of the walls. Therefore, all load bearing wall elements will be subject to some of earthquake loading applied onto the structure, proportionate to the walls respective in-plane effective lateral stiffness. This principle appears to have been adopted by the latest Concrete Code AS3600:2018 Clause 14.2.10, which states that <u>all walls connected to the diaphragm floor slab are now designated as structural walls</u>. This means that all walls will be detailed to have the level of ductility chosen for the building structure.

This is contrary to the common design assumption taken by engineers in Australia, where it has been assumed that load bearing walls within a sway-prevented structure are 'vertical load bearing' only elements and subsequently 100% of the lateral load is taken by the core walls. This approach has been demonstrated as an inaccurate and potentially dangerous assumption (Refer Ref.No:1 -Menegon et al. 2017)

The resulting design forces on walls need to be carefully considered. Regardless if the wall is a reinforced masonry wall or a concrete wall, both wall types will need to provide the same structural robustness and ductility for earthquake/wind loading and as such, the same associated steel reinforcement requirements.

This is also reflected within Section 8 of AS3700:2018 which covers the structural design of reinforced masonry, where the following statements are made:

- Clause 8.3 – *"The structural design of reinforced masonry shall be in accordance with the general principles used for reinforced concrete design, modified to suit the particular characteristics of reinforced masonry"*.
- Clause 8.4.4.1 – *"The detailing of reinforcement in reinforced masonry shall be in accordance with AS3600, except as specifically modified by Clauses 8.4 to 8.11, or Clause 5.9."* It should be noted that there are no contents within 8.4 to 8.11, or 5.9, which imply that the earthquake requirements of AS3600 should not be adopted. In fact, clause 5.9.1 states *"The detailing of reinforcement in masonry shall be in accordance with AS 3600, except as specifically modified by this clause"*

As can be seen from above, unless specified otherwise in AS3700:2018, the concrete/grout and steel reinforcement within reinforced masonry must be designed to the concrete code, AS3600:2018. There are no characteristics of reinforced masonry which enable the material to be more resistant to earthquake loading than conventional concrete. The same concrete/grout is used as the infill and in addition the masonry shells are brittle.

AS3600:2018 carefully considers the earthquake requirements for concrete walls and is dependent on the ductility classification of the structural system used in the building. Although AS3700:2018 does comprise of a section which covers design for earthquake actions (Section 10), there is no adequate explanation as to why a centrally reinforced masonry wall would have equivalent ductility to a conventional concrete wall reinforced at each face.

As stated in AS3600:2018 Section 14.1, earthquake considerations are only applicable if required by AS1170.4:2007. AS1170.4:2007 Clause 2.2 states that earthquake requirements must be considered for any structure greater than an 'Importance Level' of 1. For any low to high rise structure, or a structure where a failure could endanger human life, these earthquake requirements will apply.

AS3700:2018 Table 10.1 states that a reinforced masonry wall consists of a ductility factor (μ) ranging between 1.5-2 (as determined through testing completed by the Queensland University of Technology (QUT)) and in turn classified limited ductile walls as determined by QUT. **AS3600:2018 defines ductility types within Table 14.3; concrete walls with a ductility factor of 2 is equally considered a limited ductile wall. AS3600 states within Clause 14.6.1 that limited ductile structural walls must be provided with two layers of steel reinforcement, both vertically and horizontally.** Although this requirement is clearly stated within AS3600 for concrete walls, a similar requirement is not explicitly stated within AS3700 for reinforced masonry. This is despite the fact that AS3700 (through testing by QUT) states that centrally reinforced masonry can be designed with ductility factor of 2, which is the same as a doubly reinforced concrete wall. Therefore, there is a clear discrepancy between AS3600 and AS3700 for limited ductile walls in regards to reinforcement requirements.

The remainder of this assessment will consider whether limited ductile walls can be designed with centrally located reinforcement.

Behaviour of a wall in an earthquake is dependant on whether the connections to the slabs and the steel reinforcement is provided centrally or to each face. For central reinforcement, after being subject to cyclic loading, the connections at the top and bottom progressively establishes into a pin joint due to the central location of the bar. This can potentially lead to mechanism failure and ultimately, progressive collapse (see **Figure 1** below).

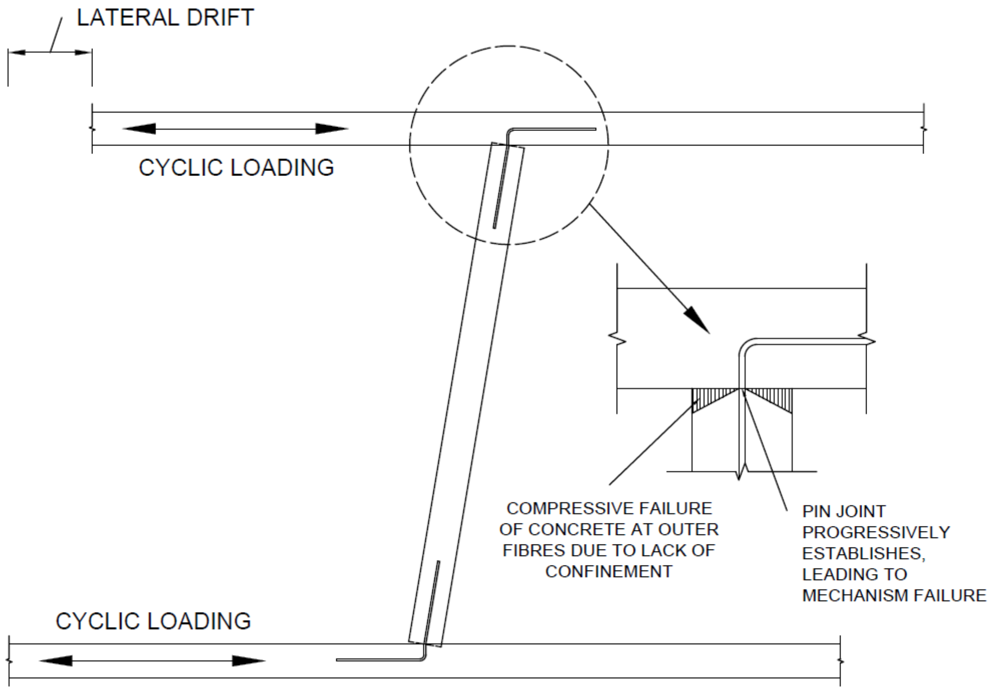

Figure 1 *– Idealised behaviour from walls with pin connection to slabs (central 'L' bars)*

To prevent a compressive failure as shown in **Figure 1**, reinforcement is required to be provided on each face, both vertically and horizontally, in order to provide confinement to the concrete. Where steel reinforcement is provided to each face, the connections can be considered fixed. For fixed connections, the wall is subject to flexural loading in order to displace concurrently with the slab (see **Figure 2**). Both wall faces are expected to be placed under tensile and compressive loading due to the cyclic reversal actions. By providing steel reinforcement to each face, it will prevent the propagation of cracks on the extreme fibres and in addition the overall ductility of the wall will be improved, allowing the wall to comply with the overall ductility requirements for the building.

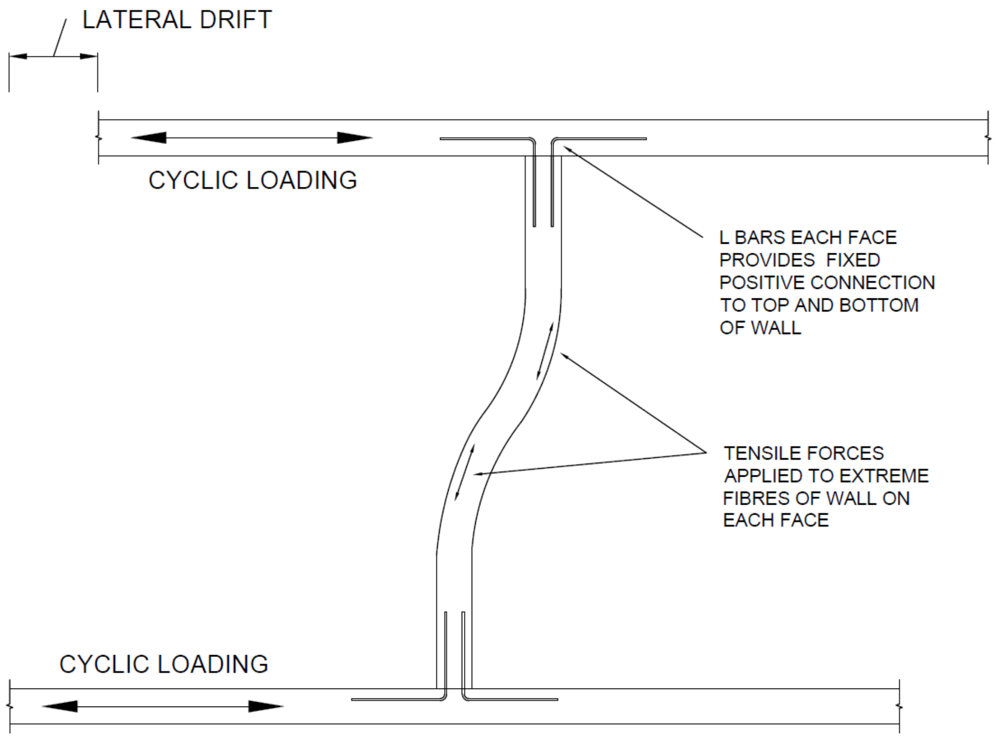

***Figure 2** – Idealised behaviour from walls with fixed connection to slabs ('L' bars to each face)*

In this scenario, tensile reinforcement is clearly required on each face in order to handle the flexural stresses induced by inter storey drift and the gravity load on the wall. **The reinforcement would be required regardless if the wall was a conventional concrete wall or reinforced masonry, as both would be exposed to the same cyclic loading and therefore the same flexural stresses. This technical assessment questions why AS3700 does not specifically detail the requirement for two layers of reinforcement, when it is clearly stated as a requirement in AS3600 and both walling types would be subject to the same earthquake loads.** The only time steel reinforcement on each face could be omitted are for highly ductile walls where the concrete is suitably confined and flexural capacity is provided through other means. However, as confirmed through testing at QUT and AS3700, reinforced masonry provides a ductility factor of up to 2 which is a limited ductile wall, not a fully ductile wall.

It is not uncommon to see reinforced masonry being used as structural walls throughout a building, with centrally placed reinforcement. However, it is clear from the above that this approach (centrally placed reinforcement) does not comply with the requirements of the latest concrete code AS3600:2018 Clause 14.6.1 and AS1170.4:2007, or provide an ability to handle the cyclic loading as demonstrated in **Figure 1. If reinforced masonry is used as structural walls for a building structure, they must therefore also be provided with two layers of steel reinforcement both vertically and horizontally.** The structural engineer must carefully consider whether this is achievable within the block work shell as due to the thickness of the masonry skin it may be difficult to achieve compacted concrete with the high quantity of steel reinforcement required. As an example, the following must be considered:

- Cover to the steel reinforcement must be more than the maximum aggregate size used in the concrete/grout mix (as stated in AS3700:2018 11.7.2.5). For most mixes, and the purposes of this assessment, the maximum aggregate size is assumed to be

10mm. Increased cover would be required for unprotected walls subject to wetting and drying.

- Spacing between parallel bars require to be 20mm, as stated in AS3700:2018 8.4.4.2. This may bear an issue for the splicing of horizontal reinforcement where such spacing would be required.
- Main (vertical) reinforcement must be surrounded by an annulus of grout with a thickness not less than twice the diameter of the reinforcement bar, as stated in AS3700:2018 8.5.1(e). Vertical reinforcement must also be placed symmetrically within the cross-section.

It is not possible to achieve all the above simultaneously where N16 bars are used within a 190mm thick block wall. Even with N12 bars, it will be difficult to maintain the above where horizontal bars are lapping (see **Figure 3**).

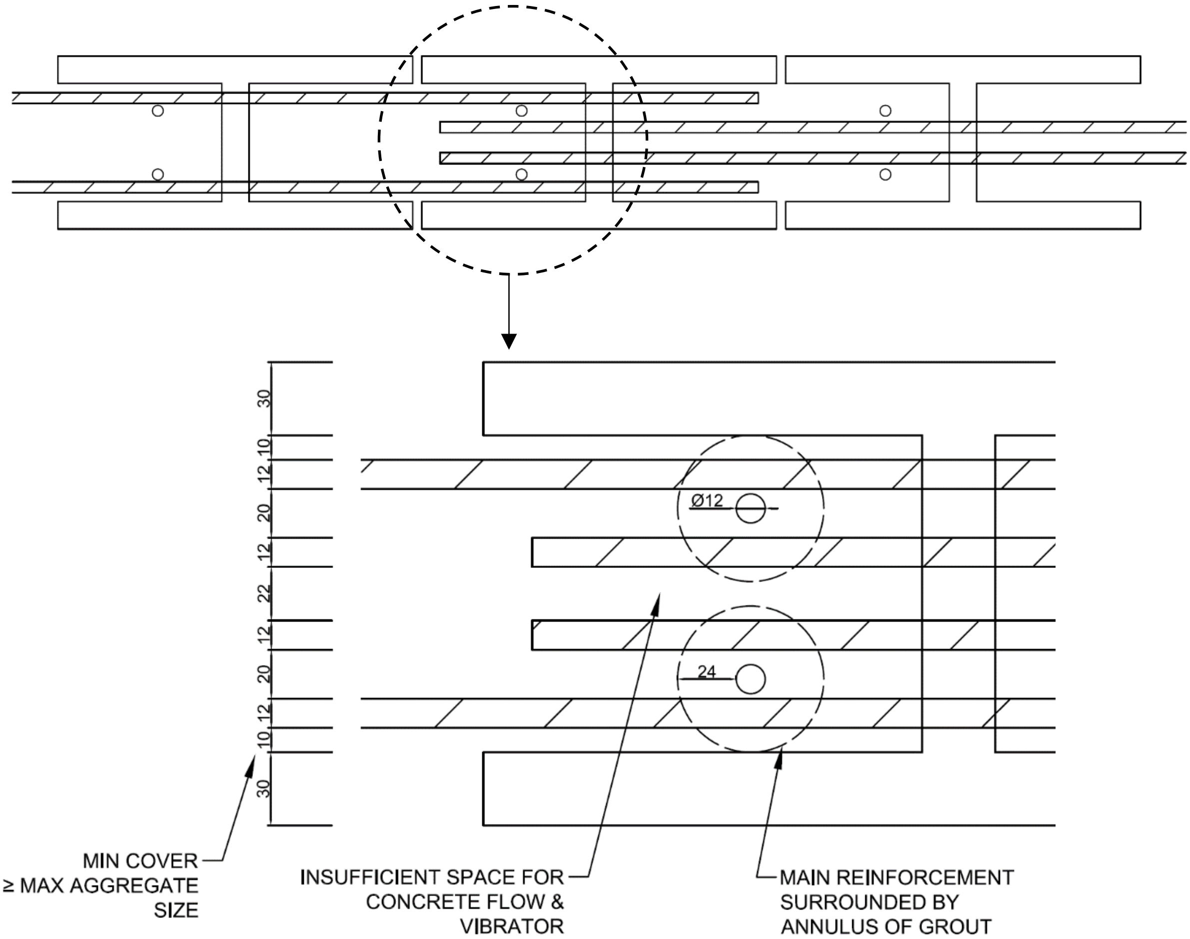

Figure 3 *– N12 Vertical and Horizontal Bars each face within a 20.48 'H' Block, at location where horizontal bars are spliced.*

Although the arrangement in **Figure 3** may be theoretically achievable on paper, concrete compaction issues (air voids) are highly likely. This issue is particularly heightened as there is not enough space to fit a concrete vibrator down the block work to compact the concrete. Additionally, in practice it would not be possible to restrain the bars in the required position as shown in **Figure 3** during the concrete/grout pour.

As an additional consideration, AS3600:2018 14.6.2.2 and 14.6.2.3 requires tie reinforcement and/or U bars for boundary elements. This will also need to be incorporated within the reinforced masonry; however, it will be inherently difficult to construct on-site.

The requirements to provide reinforcement to each face will only be possible within a minimum of 290mm thickness block walls in order to accommodate the high number of bars in its shell (see **Figure 4**). The thicker wall profile allows for room between horizontal bars to achieve adequate flow of concrete and room for a vibrator to be lowered into the wall.

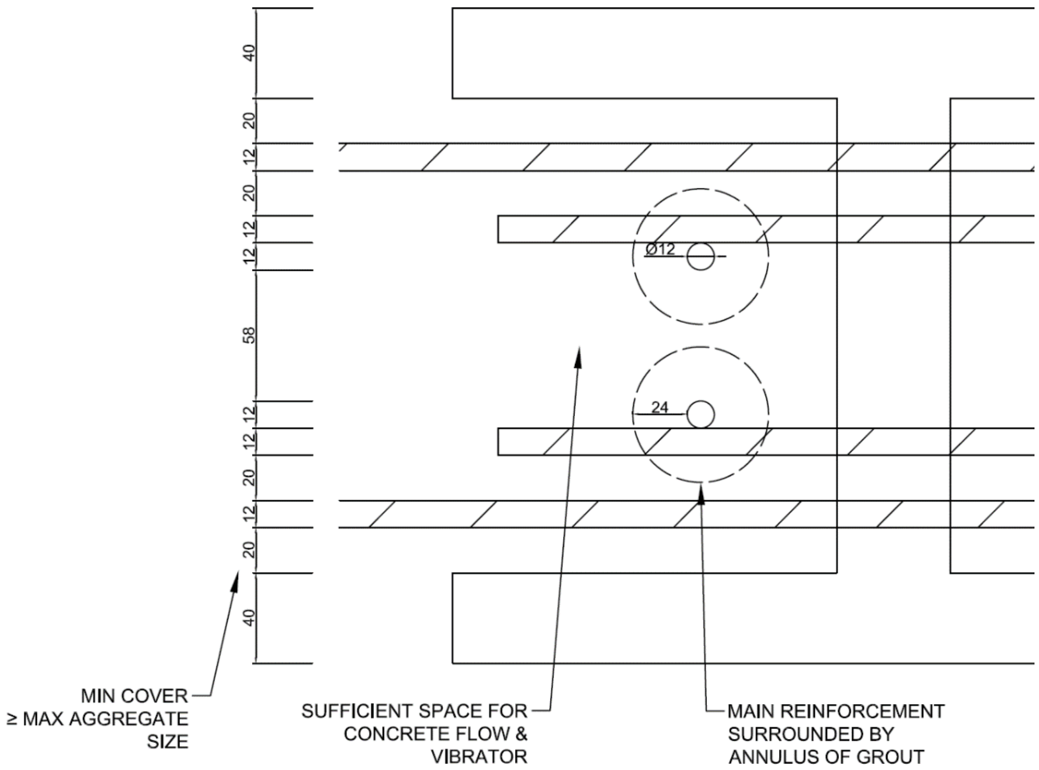

Figure 4 *– N12 Vertical and Horizontal Bars each face within a 30.48 'H' Block, at location where horizontal bars are spliced.*

It is recommended that if engineers are required to specify reinforced masonry walls in a structure where vertical and horizontal reinforcement is required to be placed at each face, a minimum 290mm block wall thickness is used to ensure adequate space for steel reinforcement and compaction of the concrete/grout (no air voids). For the reasons discussed above, a concrete wall will in most cases allow for a thinner and more structurally efficient element than reinforced masonry.

References

Menegon, Scott & Wilson, John & Lam, Nelson & McBean, Peter. 2017, RC Walls in Australia: Seismic design and Detailing to AS 1170.4 and AS 3600. Australian Journal of Structural Engineering

Standards Australia. 2018, AS3600 Concrete Structures: Standards Australia Sydney, NSW

Standards Australia. 2018, AS3700 Masonry Structures: Standards Australia Sydney, NSW