TECHNICAL NOTE

AEFAC
Australian Engineered Fasteners and Anchors Council

AEFAC – TN13

GUIDELINES FOR PRECAST WALL TO SUSPENDED SLAB CONNECTIONS

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Revision Sheet

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0		Initial release	July 2023

1. Introduction

Designers usually assume that continuity of the reinforcement is achieved at the concrete wall and concrete slab connections. In cases where the wall is cast at an earlier time compared to the slab, e.g., when precast walls or in-situ walls with a jump-form formwork are used, continuity of the reinforcement around the connection becomes a challenge.

Traditional precast wall to suspended floor details have utilized cast-in proprietary reinforcement systems with re-bent bars to form a connection between the walls and slabs. These proprietary systems are mostly limited to bars with a diameter of 12mm as re-bending of bar with larger diameters is not practical and introduces health and safety risks for the installer.

Alternate methods of precast wall to suspended floor details need to achieve the same ductile connection for which a continuous reinforcement would provide. Recently, there have been some instances where incorrect methods have been used, such as cast-in inserts with shallow embedment depths, that cannot achieve a ductile connection.

2. Scope

The aim of this technical note is to provide insight to designing precast wall to suspended slab connections. It addresses a possible non-compliant use of threaded inserts (also referred to as ferrules) as a headed anchor for reinforcing bars in the connection between precast walls and in-situ suspended slabs. The substitution with a system which has insufficient capacity to achieve a ductile connection due to the shallow embedment of the threaded insert will not fulfill the design intent of AS 3600 [1] and AS 5100 [2], both of which require a ductile failure mode.

This technical note covers the connection between precast walls and in-situ suspended slabs. However, it equally applies to in-situ wall to in-situ suspended slab connections where the in-situ wall is built prior to the slab (e.g., jump-form construction). The advice provided in this document also applies to in-situ band beam connections to precast or in-situ walls.

The guidance provided in this note also applies to other civil and construction applications that require continuity of reinforcement between two consecutive concrete pours.

3. Terminology

The following terminologies and definitions are used in this Technical Note. Please refer to AS 5216[3] and AEFAC Anchor Dictionary [4] for additional terminologies and definitions.

Metric threaded insert (Ferrule): These are cast-in headed anchors with internal threads normally designed to be used with Grade 4.6 threaded bolts.

Proprietary continuously threaded reinforcing bars: These are Grade 500N reinforcing bars with proprietary continuous thread which can be connected using proprietary threaded couplers which are designed to exceed the capacity of the reinforcing bar. These connections need to comply with the requirements defined in section 13.2.6 of AS 3600 or AS 5100.5. A Proprietary continuously threaded reinforcing bar is shown in Figure 1.

Figure 1: Proprietary continuously threaded reinforcing bars

Proprietary reinforcement cast-in systems with re-bent bars: These are proprietary reinforcement cast-in systems with re-bent bars normally consist of a box-section to provide a recess in the concrete member that is poured first. They include reinforcing bars that are bent into the box and once straightened provide continuity of reinforcement by developing into the second pour. Figure 2 shows cast-in systems with re-bend bars.

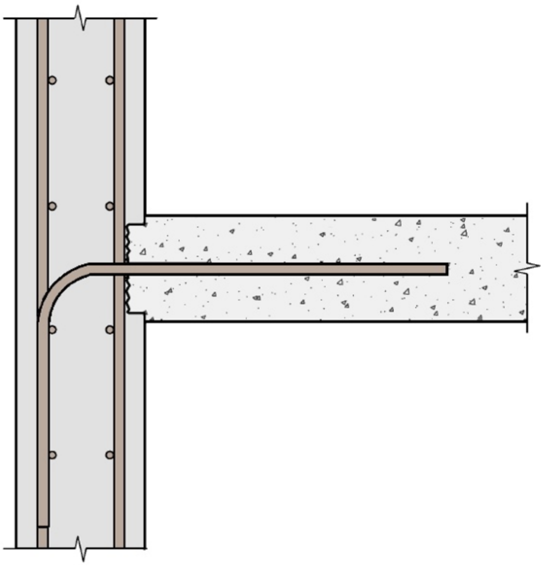
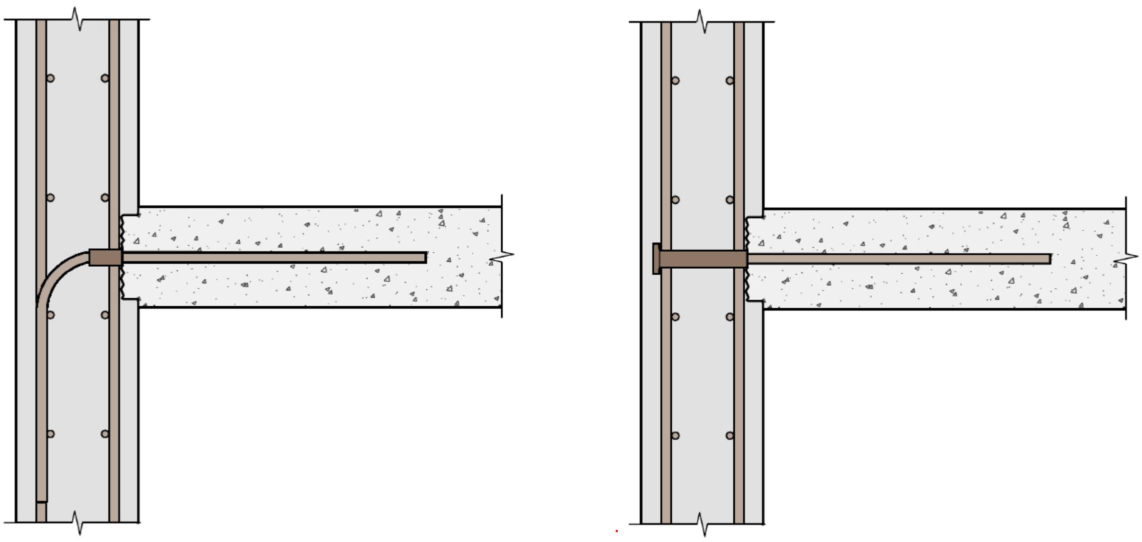


Figure 2: Proprietary reinforcement cast-in systems with re-bent bars

Proprietary reinforcing bar couplers: Proprietary reinforcing bar couplers, also called mechanical splices, are systems that connect reinforcing bars to each other or connect reinforcing bars to deep headed fastener using a threaded connection that provides bar break as shown in Figure 3. These systems use rolled or cut threads that are manufactured in a way that the connection capacity exceeds the capacity of the parent reinforcement bar. These connections need to comply with the requirements defined in section 13.2.6 of AS 3600 or AS 5100.5.



(a) Coupler Connection *(b) Anchor Connection*

Figure 3: Proprietary reinforcing bar couplers

4. Precast wall to in-situ slab connections

4.1 Traditional connection

The detail of the traditional slab to wall connection is presented in Figure 4.

The capacity of the reinforcing bar should be checked as per guidelines provided in section 13.1.2.7 of AS 3600. Depending on the thickness of the wall, full development of the reinforcing bar might not be possible to achieve. AS 3600 mandates the use of a specific tool for the purpose of re-bending reinforcing bars without causing non-conforming bend diameter.

An inherent problem of the re-bent bars is the difficulty of site re-bending and the associated health and safety concerns to the site personnel. If re-bending of the reinforcing bar is not carried out as per guidelines provided in AS 3600, it can compromise the integrity of the reinforcement bar.

An alternative method to re-bent bars is a cast-in system which enables onsite installation of starter bars into the cast-in system within the wall.

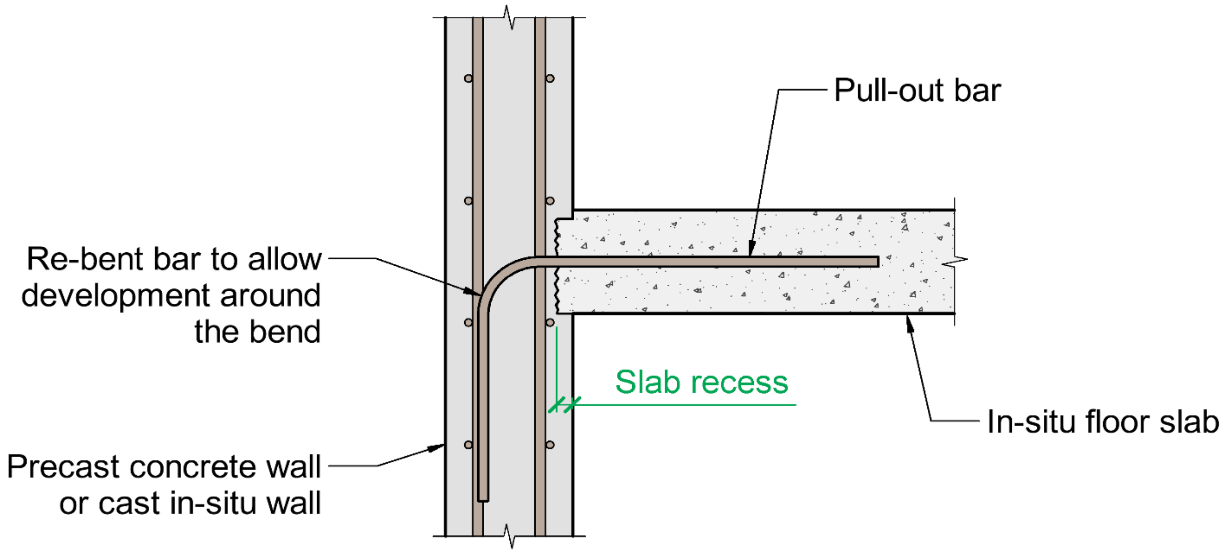


Figure 4: Traditional slab to wall connection with re-bent bars.

4.2 Cast-in Threaded Insert Connection System

Pull-out bars (as shown in Figure 4) were traditionally the industry standard for slab to wall connections, however, in recent years threaded inserts have become more popular. Figure 5 shows a typical slab to wall connection with threaded insert.

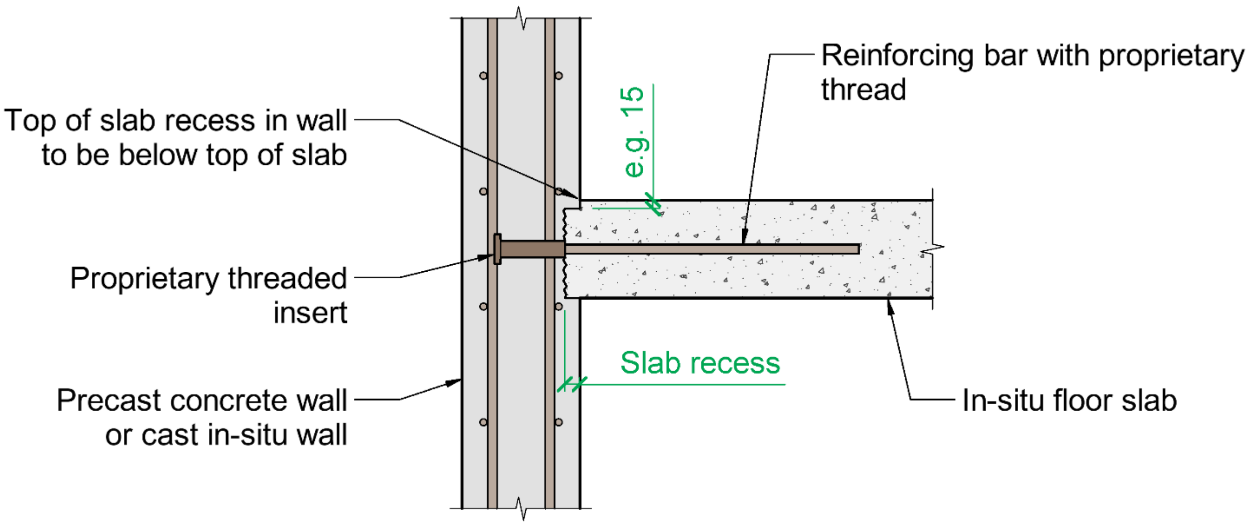


Figure 5: typical slab to wall connection with threaded insert.

Proprietary threaded inserts can successfully be used to achieve the capacity and ductility required for a slab to wall connection provided they are designed properly. It is imperative that the designer utilizes the supplier's technical information to perform the required calculations that demonstrate the threaded inserts have sufficient embedment depth. Figure 6 provides an illustration highlighting the desired and undesired failure modes.

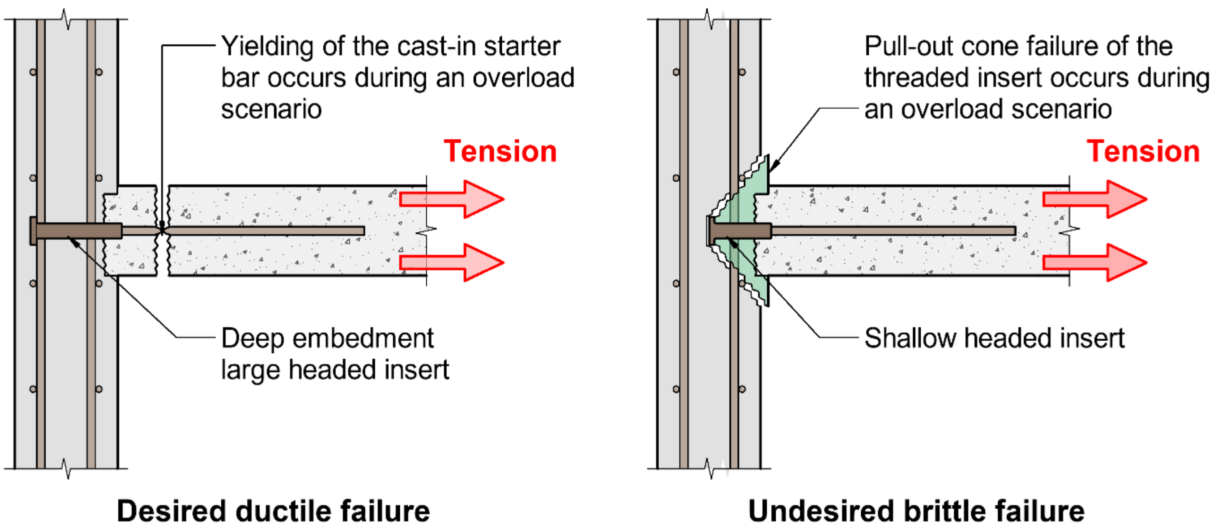


Figure 6: Failure modes of headed anchor connections.

4.3 Proprietary reinforcing bar coupler system with cogged bar

A connection utilising a cast-in coupler with a cogged bar is shown in Figure 7, which could be detailed identically to a fully in-situ wall to slab connection.

For applications with cogged bars and couplers at the surface of the prefabricated concrete wall, proprietary reinforcing bar couplers or proprietary continuously threaded reinforcing bars need to be used. The use of generic reinforcing bars with standard metric threads cut into them creates a potential stress concentration and provides a reduced capacity that results from threads cut into tempcore reinforcing bar such as Grade 500N.

When designing cogged bar connections with couplers, it is imperative the designer utilizes the technical information provided by the system supplier to perform the required calculations that demonstrate the cast-in coupler and cogged bar system has sufficient development length and associated bend diameter as per guidelines provided in section 13.1.2.7 in AS 3600.

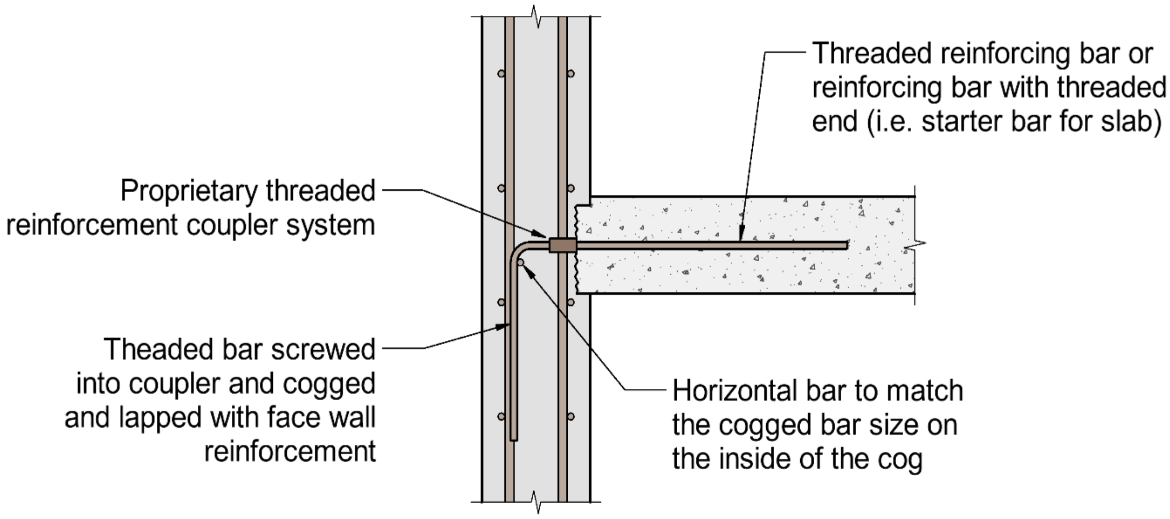


Figure 7: cast-in coupler with cogged bar connection system.

5. Non-compliant Precast wall to in-situ slab connections

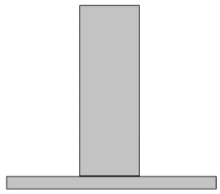
5.1 Examples of Non-compliant systems

Figure 8 shows some examples of threaded inserts (ferrules) that are designed to provide anchorage for metric bolted connections, normally of Grade 4.6, to reinforced concrete. When used in conjunction with metric threaded reinforcing bars, they provide a connection that is non-compliant with the design intent of AS 3600. This is due to the shallow embedment depth of the anchor which will typically results in a non-ductile failure mode.

Round bar Ferrule (plain threaded insert) with cross-hole

Tube Ferrule with cross-hole

Any Shallow embedment depth ferrules



Any Bespoke ferrule with no supporting test data

Figure 8: Examples of non-compliant systems.

Figure 9 shows the details of an M16 round bar ferrule (plain threaded insert) with N12 x 300 cross bar to create anchorage. The starter bar connecting to it is an N20 reinforcing bar with an M16 thread cut into it to suit the ferrule as depicted in Figure 10. Although there is a rebate of 35mm, the anchorage is still considered to be shallow given the intended reinforcing bar size required in the detail.

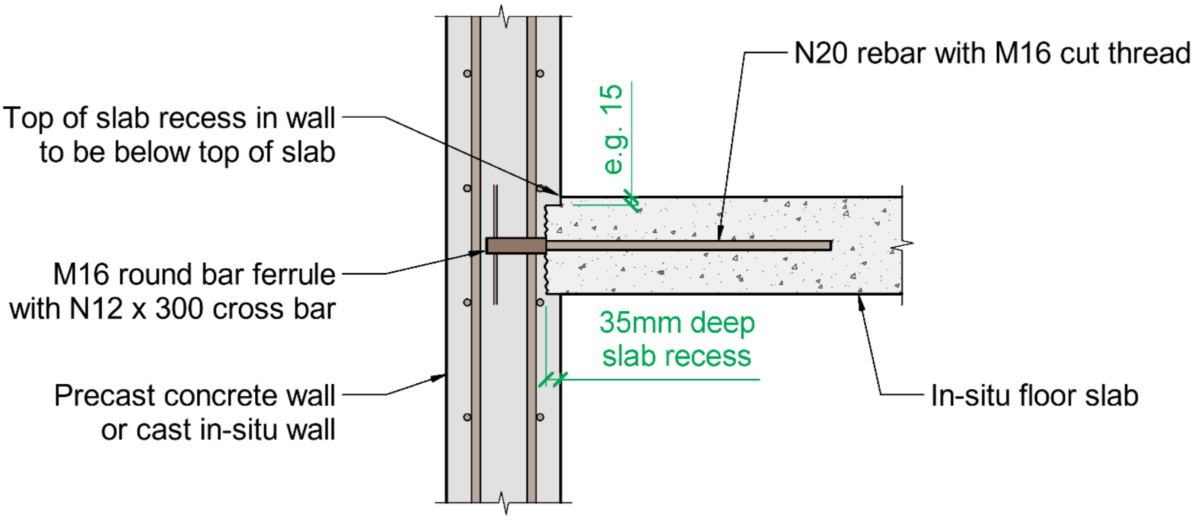


Figure 9: Plain threaded inserts with cross-hole connection system.

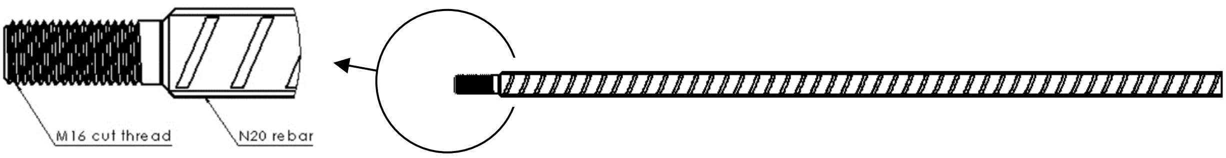


Figure 10: N20 reinforcing bar with metric M16 thread.

6. Acknowledgement

The Australian Engineered Fasteners and Anchors Council (AEFAC) acknowledges the valuable technical contributions from Prof. Shan Kumar and Dr. Scott Menegon towards the development of this Technical Note.

7. References

[1] Standards Australia, AS 3600: Concrete structures, SAI Global, Sydney, 2018.

[2] Standards Australia, AS 5100 Series: Bridge design Scope and general principles, SAI Global, Sydney, 2017.

[3] Standards Australia, AS 5216: Design of post-installed and cast-in fastenings in concrete, SAI Global, Sydney, 2021.

[4] AEFAC, Technical Note, "AEFAC Anchor Dictionary," Australian Engineered Fasteners and Anchors Council. www.aefac.org.au.

[5] CEN (European Committee for Standardization). (2018). EN 1992-4: Eurocode 2: Design of concrete structures - Part 4: Design of fastenings for use in concrete. Brussels: CEN

[6] ACI (American Concrete Institute). (2019). ACI 318: Building code requirements for structural concrete (ACI 318M-19) and commentary (ACI 318RM-19). Michigan: ACI

[7] Standards New Zealand, NZS 3101: Concrete structures standard, Standards New Zealand, New Zealand, 2006.

[8] Standards Australia, AS 3850.1: Prefabricated concrete elements General requirements, SAI Global, Sydney, 2015.

Appendix A –Worked Example - shallow embedment depth inserts.

The following is an example of a concrete capacity calculation for shallow embedment depth threaded inserts using the Concrete Capacity Design (CCD) Method. The CCD Method is utilized by international standards such as EN 1992-4 [5], ACI 318 [6], NZS 3101 [7], AS 3850.1 Appendix B [8] and AS 5216 [3]. For the purpose of this exercise, the data from ACI 318 Chapter 17 has been utilised which is suitable for cast-in headed anchors and is closely aligned with NZS 3101 and AS 3850.1 whereas EN 1992-4 and AS 5216 are only applicable for cast-in channels.

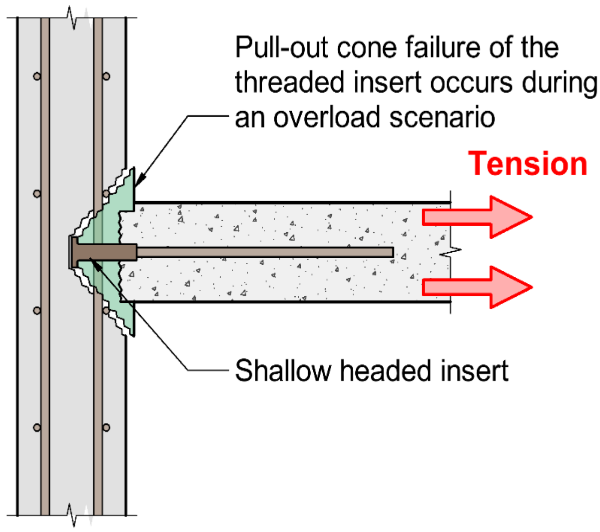


Figure 11: Connection with shallow insert resulting in undesired brittle failure mode

- Effective Length of ferrule, L_{ef} = 90mm
- Rebate depth of precast panel, x = 35mm
- Effective Depth, $h_{ef} = L_{ef} + x$ = 125mm
- Anchor spacing of ferrule, s_1 = 200mm
- Edge distance of ferrule, c = No influencing edge
- Concrete Compressive Strength, f_c' = 40 MPa
- Reinforcing Bar Size, d_b = 20mm (N20 reinforcing bars)

A.1 Concrete Capacity Calculations

Characteristic concrete cone tensile capacity of a single insert

$$N^0_{Rk,c} = k_1\sqrt{f_c'}h_{ef}^{1.5}$$

where

- k_1 = $k_{cr,N}$ for cracked concrete; $k_{ucr,N}$ for uncracked concrete
  - $k_{cr,N}$ = 10
  - $k_{ucr,N}$ = 12.5
- $f'c$ = characteristic compressive strength of the concrete in the wall (maximum value of 40 MPa typically in precast wall panels)
- h_{ef} = effective depth of the insert = 125mm (refer above)

Therefore, assuming cracked concrete condition

$$N^0_{Rk,c} = 10\sqrt{40}\ 125^{1.5}$$

$$N^0_{Rk,c} = 88.4\ kN$$

Assuming multiple anchors in a row, we need to allow for geometric effect of the edge distance and spacing effects.

The theoretical projected area of the concrete cone is calculated using the following equation with definition of notations depicted in Figure 12.

$$A^0_{c,N} = \left(S_{cr,N}\right)^2 = \left(3h_{ef}\right)^2 = (3 * 125)^2 = 140{,}625\ \text{mm}^2$$

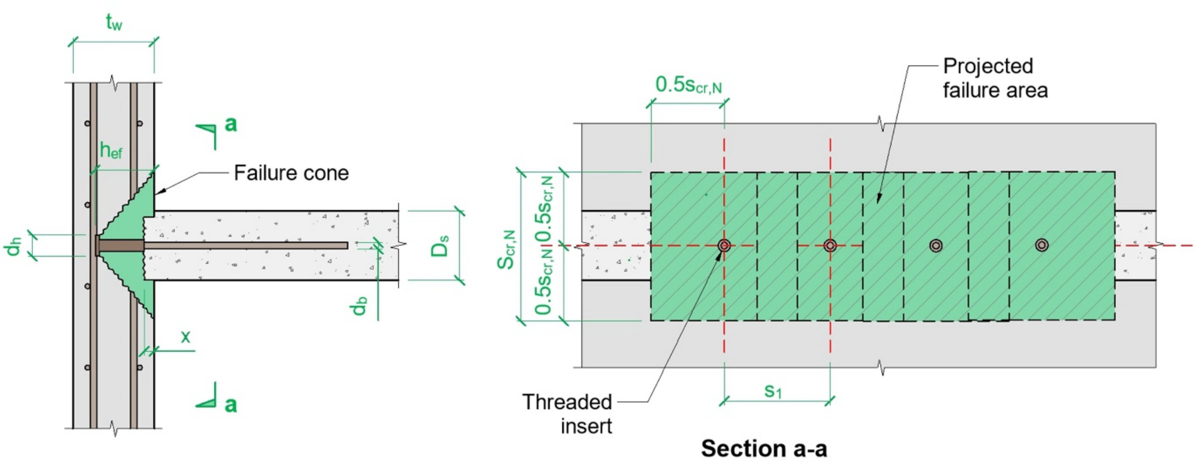


Figure 12: Concrete cone failure in precast wall.

The actual projected area of the threaded inserts is the failure cone that is limited by the overlapping failure cones of adjacent inserts. For a connection with multiple threaded inserts with s_1= 200mm and no edge distance effects, the area of the actual projected area is calculated as follows:

$$A_{c,N} = S_{cr,N} * s_1 = 3 * 125 * \ 200 = 75{,}000 \text{ mm}^2$$

For a group of threaded inserts, the characteristic strength for concrete cone failure is as follows:

$$\phi_{Mc} N_{Rk,c} = N^0_{Rk,c} \left(\frac{A_{c,N}}{A^0_{c,N}} \right) \psi_{s,N} \psi_{re,N} \psi_{ec,N}$$

where,

- $N^0_{Rk,c}$, $A_{c,N}$ *and* $A^0_{c,N}$ have been defined earlier
- $\psi_{s,N} = 1.0$ (Parameter accounting for the disturbances of stress in the concrete due to the close proximity of the threaded insert to a corner of the concrete member) – no influencing corner or edge therefore 1
- $\psi_{re,N} = 0.5 + \frac{h_{ef}}{200} = 0.5 + \frac{125}{200} \geq 1$ (Parameter accounting for a shell spalling)
- $\psi_{ec,N} = 1.0$ (parameter accounting for eccentricity of the resultant load in a fastener group) – only accounting for single row two anchors therefore 1

Therefore, the capacity for an anchor considering group and other effects,

$$\therefore \ N_{Rk,c} = 88.4 * \left(\frac{75{,}000}{140{,}625} \right) * 1.0 * 1.0 * 1.0 * 1.0 = \mathbf{47.1\ kN}$$

A.2 Reinforcement bar capacity

N16 Grade 500N reinforcing bar has nominal cross-sectional area of 201 mm^2 and a characteristic yield strength of 100.5 kN.

If N20 bar is used with a cut M16 thread in combination with an M16 threaded insert in the precast wall, the thread reduces the cross section to 157mm^2. However, because Grade 500N reinforcing bar can be manufactured using the Tempcore process, the strength of the bar is inconsistent throughout its cross section, with the core being weaker compared to the periphery. Based on a strength reduction of 25%, the characteristic yield strength of the bar along the thread is only **58.9 kN.**

Therefore, the use of this type of starter bar will result in localized deformation and failure through the thread section is only about **60% of the capacity of unmachined N16 bar.**

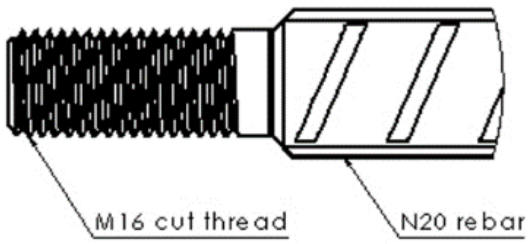


Figure 13: M16 cut thread on N20 rebar.

A.3 CCD vs reinforcement bar capacity for shallow embedment depth inserts

CCD Capacity from section A.1,

- **$N_{Rk,c}$ =47.1 kN per anchor**

Rebar Capacity from section A.2,

- **$N_{Rk,s}$ = 58.9 kN per anchor**

Without further calculating design capacities (i.e., applying capacity reduction factors – ϕ_{Mc} and ϕ_{Ms}), it is clear that the concrete capacity is the limiting case for the threaded inserts with shallow embedment. As such, the connection will fail in non-ductile manner. Furthermore, the reinforcement bar capacity is much lower than it's intended capacity of an N16 bar even though an N20 bar was used with an M16 cut thread. This also demonstrates that this type of connection detail is non-compliant and must not be detailed and constructed.

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