

New ICC/ACI Design Concept for Post-Installed Reinforcement Bars

Kelly Chua, B.Eng (Civil and Structural)

ABSTRACT: Post-installed reinforcement bars have always been used in structural joints of reinforced concrete elements, either through design or as a method of rectification for missing or misaligned cast-in reinforcement bars. It has traditionally been confused with post-installed anchors used in a base plate connection. Strictly speaking, when installing reinforcement bars to join one reinforced concrete element to another, a different design concept has to be applied as there are very different conditions to consider. This paper will discuss the differences between the anchor and rebar design concepts, and the latest revisions to the Acceptance Criteria for Post-Installed Adhesive Anchors in Concrete Elements, AC308, and the American Concrete Institute code, ACI 318, that are relevant to the design of post-installed reinforcement bars used in construction joint connections .

1. INTRODUCTION

Construction joints are part of a reinforced concrete structure and traditionally, cast-in options have mostly been used in order to ensure that the reinforcement within the structure is linked through a construction joint in order to ensure the entire structure is monolithic. However, in cases where changes to an existing structure has to be made or when mistakes in the arrangement of the cast-in bars happen, post-installed reinforcement has to be used. This means the installation of reinforcing bars grouted into drilled holes, usually with injectable adhesives.

Previously, in the design of reinforcing bars installed in such a way, reference was made to ACI 318-11 Appendix D, *Anchoring to Concrete*. Appendix D contained provisions to calculate the strength of such connections corresponding to various anchor failure modes. However, these design provisions were assuming the bars are acting as “anchors”. This meant that the post-installed reinforcement bars are assumed to be transmitting tension and shear stresses directly on to the concrete surrounding the installed bar.

In a construction joint, the reinforcement bars transmit forces in a different way. This paper will discuss on the differences in an anchor connection as compared to the post-installed reinforcement used in a construction joint and the latest design provisions within the ACI 318-14, Building Code Requirements for Structural Concrete, and AC308, Acceptance Criteria for Post-Installed Adhesive Anchors in Concrete Elements

2. ANCHOR DESIGN VS REINFORCEMENT BAR DESIGN

The Concrete Capacity Design (CCD) used in anchor design is a series of checks to determine the capacity of an anchor by means of calculating the capacities of various failure modes and determining the failure mode that will be most critical. This method involves the calculation of the various failure modes in both tension and shear.

Reinforcement bars in a construction joint behave differently. The two diagrams below depict two situations where one is a base plate connection (Figure 1) and the other is a post-installed rebar connection forming a construction joint (Figure 2). Both are of a beam to wall connection where the new structural element (beam) is connected to an existing one (wall).

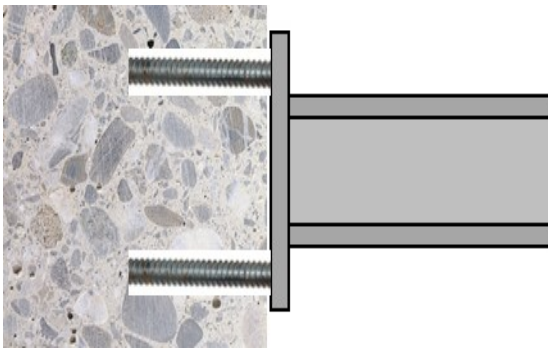


Figure 1

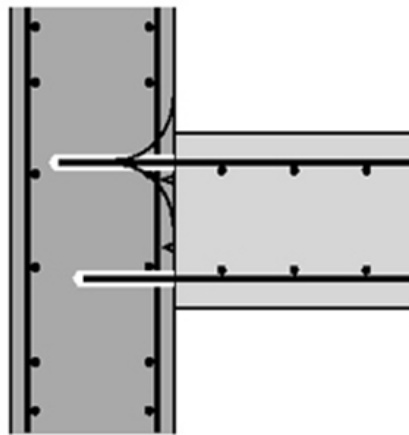


Figure 2

2.1. Base Plate Connection (Figure 1)

A base plate connection joints a steel element (base plate) to a concrete base material. A connection such as this is considered smooth, leading to shear forces being transferred directly on to the anchors and then on to the concrete base material. Tension stresses will also be directly transferred on to the concrete. Hence, with concrete taking up all of the stresses coming in from the steel element, the failure modes that need to be checked are mostly from the capacity of the concrete which are as follows:

Tension failure modes

- Steel breakage
- Pullout of the anchor
- Concrete breakout
- Concrete splitting

Shear failure modes

- Shearing of steel
- Concrete edge breakout
- Concrete pryout

The checking of these failure modes is what is known as the anchor theory.

It is also important to note that all of these failure modes are modelling the transfer of stresses directly on to the concrete and they do not utilize the existing reinforcement to transfer tensile loads.

2.2. Reinforcement Bar Connection (Figure 2)

A reinforcement bar connection joints one concrete element to another. It is also known as a construction joint. The stresses on this type of connection are very different from a base plate connection.

2.2.1 There is no shear stress transferred from the new concrete element to the existing one

In a construction joint, the following is generally true:

- Joint surfaces are roughened
- New concrete will bond with existing concrete

Hence, unlike the base plate connection, any shear forces in the connection will actually develop tension in the reinforcement bars through the strut and tie model. This is best illustrated by the figure below.

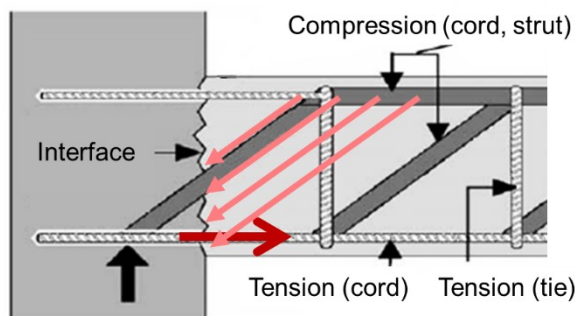


Figure 3

Figure 3 shows a simply supported connection where there is only shear at the node and no moments. Even with only shear, through a strut and tie model, the bottom layer of reinforcement bars will be transferring tension stresses to the existing concrete. The tension force along the bottom layer of reinforcement bars is calculated using the following formula:

$$F^V = \frac{V}{2} \cot \theta$$

Where V = shear force at the node
 θ = assumed angle of strut
 F^V = tension on bottom bars

In a fixed connection (moment connection), the tension stresses will be depending on the direction of the moment. In the example below, the tension forces will be along the top layer of reinforcement bars.

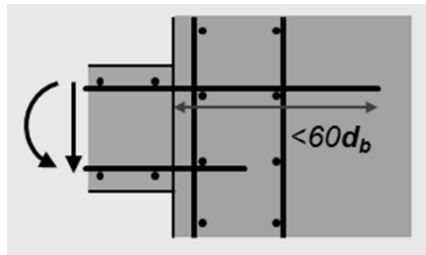


Figure 4

2.2.2 To transfer tensile loads, post-installed reinforcement utilizes the existing cast-in reinforcement

In reinforced concrete design, it is fundamental to remember that the main reinforcement of every concrete element is designed to the yield strength of the reinforcement bars. This is to ensure that the structure fails in a ductile manner when the reinforcement bars take up the tension stresses within the concrete elements.

In order to ensure a post-installed connection transfers stresses in the same way as a cast-in connection, post-installed reinforcement bars must also be designed to fail in a ductile manner. And because post-installed reinforcement bars only transfer tensile loads in a concrete to concrete connection, it is important to ensure that the load transfer of these tension stresses will not cause a brittle failure.

To ensure that, post-installed reinforcement bars have to be designed to transfer tensile stresses on to existing reinforcement within the concrete via lap splices. Without lap splices, the tension stresses will be transferred directly on to the concrete through compression struts and this will result in a brittle concrete failure. This difference is highlighted in the following figures.

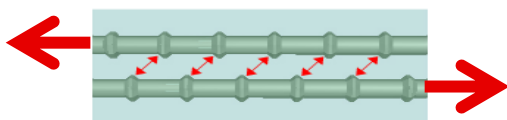


Figure 5

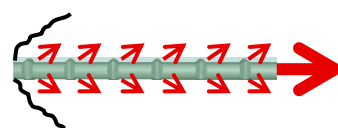
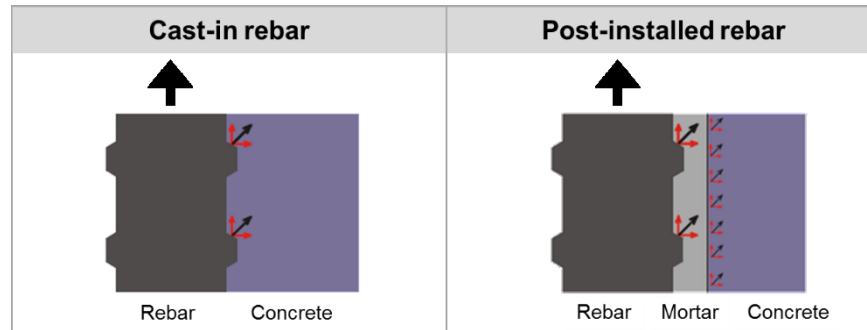


Figure 6

Without lap splicing

2.2.3 Load transfer of a post-installed reinforcement bar must be equivalent to cast-in reinforcement bars

Concrete is a relatively stiff and brittle material. A cast-in reinforcement bar design according to code requirements has direct mechanical interlock between the bar and the concrete. A post-installed reinforcement bar however, has a layer of adhesive between the reinforcement bar and the concrete substrate. This is best illustrated by the figure below.



Hence, in order to ensure that the post-installed reinforcement bar transfer stresses in the same manner as a cast-in reinforcement bar, the mortar or adhesive used in a post-installed solution must be checked for the stiffness behavior and the adhesion properties. This is especially true of mortars or adhesives which are of the epoxy type. An epoxy material has a very elastic behavior which causes displacement, a phenomena known as creep. It is vital that this behavior in epoxies are checked if an epoxy mortar is used in a post-installed connection.

3. POST-INSTALLED REINFORCEMENT BAR DESIGN ACCORDING TO LATEST AC 308 AND ACI 318-14

In consideration of the differences between an anchor connection and a post-installed reinforcement bar connection, AC 308 was revised in recent years to include provisions for determining the suitability of mortars or adhesives for the post-installed reinforcement bar connections. The latest edition provides a comprehensive test programme specific for post-installed reinforcing bar connections in order to ensure that the mortar has a similar load transfer behavior to concrete. The programme also includes tests to determine the sensitivity to installation which will be critical at deep embedment lengths. These tests are listed out in Table 3.8, of which the latest revision includes cyclic tension tests at a higher frequency in order to qualify the mortar for seismic conditions as well.

Once a mortar has been suitably qualified to be used, the post-installed reinforcement bar can then be designed according to ACI 318-14 rules for cast-in place reinforcing bar development. In designing for structural concrete, all reinforcement is designed to develop

the yield of the bar. Hence, when designing for post-installed reinforcement according to ACI 318, the embedment depth required of a post-installed bar is the development length required of a cast-in bar.

The general equation for development length of starter bars in tension is given in Equation 25.4.2.3a under Clause 25.4.2.3 in ACI 318-14 as below:

$$\ell_d = \left(\frac{f_y}{1.1\lambda\sqrt{f'_c}} \frac{\Psi_t\Psi_e\Psi_s}{\left(\frac{c_b + K_{tr}}{d_b} \right)} \right) d_b$$

where K_{tr} is given in Equation 25.4.2.3b in the same clause. It is also important to note that the confinement term $(c_b + K_{tr})/d_b$ is not allowed to exceed 2.5. As a design simplification, $K_{tr} = 0$ can be used even if transverse reinforcement is present. The rest of the modification factors in Equation 25.4.2.3a are given in Table 25.4.3.4 of the ACI 318-14.

For starter bars in compression, the equations are given under Clause 25.4.9.2 where the development length is calculated by (a) or (b) as follows depending on which is greater

$$(a) \left(\frac{0.24f_y\Psi_r}{\lambda\sqrt{f'_c}} \right) d_b$$

$$(b) 0.043f_y\Psi_r d_b$$

The modification factors used in these equations are given in Table 25.4.9.3 of the ACI 318-14.

4. CONCLUSION

Post-installed reinforcement bars are a widely accepted form of rectification, very often done to replace reinforcement bars that were initially designed to be cast-in. These bars are always used in structural connections and it is critical for a structural engineer to always keep up with the latest in code revisions governing connections such as these.

The latest revisions in the acceptance criteria AC308 (Jan 2016) and the ACI318-14 now show specific clauses referring to these type of connections and proving that these connections have to be designed with a separate model that will ensure the post-installed bars perform in the exact same manner as cast-in ones if the structural engineer designs it so. As these latest revisions represent the state-of-the-art solution, engineers should refer to these revisions when designing their structures in order to ensure code compliance and provide the best solutions.

5. REFERENCES

- International Code Council Evaluation Service (ICC-ES). *Acceptance Criteria for Post-Installed Adhesive Anchors in Concrete Elements (AC308, Jan 2016)*, USA.
- American Concrete Institute (ACI), 2011. *Building Code Requirements for Structural Concrete (ACI 318-11) and Commentary*, Farmington Hills, Michigan/USA.