MANAGING TOLERANCES AND ALIGNMENT OF CONNECTIONS IN MODERN CONCRETE CONSTRUCTION

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Abstract: Australian construction standards allow maximum tolerances for different connection applications. For example, when connecting a precast concrete panel there are allowable tolerances of +5mm for the panel dimensions, the position of the ferrules, the spacing of the ferrules, the hole positions in the steel, panel set out positions on site and the panel footing on site. It is engineering best practice to limit cumulative tolerances to no greater than 20mm and in fact AS 3850.2:2015 Prefabricated concrete elements (1) has this limit as a requirement.

Furthermore, the 21st century construction site demands a higher level of accuracy than ever before. Prefabricated concrete and steel assemblies, along with façade and curtain walling systems, require the ability to adjust the connection point while achieving millimetre precision.

The advent of modern surveying technology has resulted in the expectation for a higher level of precision in construction. This expectation, along the adoption of efficient off-site construction has resulted in the need for adjustability and precision in construction connections that allow for rapidly rolling construction programs on-site while addressing the tolerance stack up often associated with traditional structural connections.

This paper examines the tolerance and alignment challenges that the construction site faces and considers the various methods employed to provide a solution. These include the use of cast-in plates and channels, oversized holes and washers, post-installed anchoring, and an innovative orbital plate washer assembly.

Keywords: Precast, connection, tolerance, joint, alignment.

Introduction

Australian construction standards allow maximum tolerances for different connection applications. For example, when connecting precast concrete panels, AS 3850.2:2015 (1) section 2.11 TOLERANCES, states "the effects of cumulative tolerances shall be considered. The total accumulation of tolerance shall be not greater than 20 mm when related to set-out grids and data."

Therefore, the design engineer is responsible for ensuring sufficient tolerance is available in the joints to be used to assemble the precast units on site.

Table 2.5 in AS 3850.2:2015 (1) gives the tolerances on as cast elements, detailing the acceptable deviations in linear dimensions, positions of individual connection bolts and longitudinal locations of any group of bolts. When adding these three individual tolerances to those required between elements, it is quickly understood that even 20mm tolerance can be a challenge to achieve.

Furthermore, the 21st century construction site demands a higher level of accuracy than ever before. Prefabricated concrete and steel assemblies, along with façade and curtain walling systems, require the ability to adjust the connection point while achieving millimetre precision.

The advent of modern surveying technology has resulted in the expectation for a higher level of precision in construction. This expectation, along the adoption of efficient off-site construction has resulted in the need for adjustability and precision in construction connections that allow for rapidly rolling construction programs on-site while addressing the tolerance stack up often associated with of traditional structural connections.

Precast panel manufacturing practices see panels that are < 24 hours old, lifted from the casting bed and placed in storage racks where they cure from approximately 15 MPa up to 40 MPa plus. Differential curing rates on the two faces caused by variances in air circulation or proximity of other panels, often results in panels developing a longitudinal bow. All too often this happens in different directions or to different degrees in adjacent panels creating an unsightly misalignment in the middle of the panels.

Hot work on a building site represents both an OH&S challenge and is very time consuming and expensive. Modern precast modular construction therefore sees welding, grinding, oxy cutting and all other hot work associated with custom fitting and welding steel work being avoided wherever possible.

Durability in buildings is a critical consideration when choosing connections in any domestic or commercial construction project. Referring to the ABCB, Durability in Buildings including Plumbing Installations 2015 second edition Handbook (2), gives some guidance for the design engineer. Table 3-1 defines a Normal Building Design Life category as being 50 years and the design life for components or sub systems not accessible or not economical to replace or repair (within that building) as being 50 years. Connections in precast concrete buildings are not considered replaceable or repairable so for a Normal category building design life, the connections will need to have a 50-year design life.

AS/NZS 2312.2:2014 Guide to the protection of structural steel against atmospheric corrosion by the use of protective coatings (3), part 2: Hot-dip galvanizing, can assist designers to choose the correct coating for the connections in their project. Tables 6.1 & 6.2 detail typical atmospheric environments (indoors and outdoors) and the respective life to first maintenance for a selection of coating systems in a range of corrosion categories.

Where hot-dip galvanized items are to be welded on site, AS/NZS 2312.2:2014 (3) section 7.3.2.2 gives 2 options for the repair required after welding, to maintain the desired design life. The first being two coats of a zinc rich epoxy paint (min 50 µm DFT per coat), the second an inorganic zinc silicate paint complying to AS/NZS 3750.15 Paints for steel structures Inorganic zinc silicate paint (4) achieving a min 100 µm DFT.

There are many current solutions to connecting panels that address these challenges in different ways that the design engineer has to choose from to meet the specific requirements of the particular building project.

Connection Solutions

Cast-in Plates

Figure 1 cast in plate prior to concrete pour

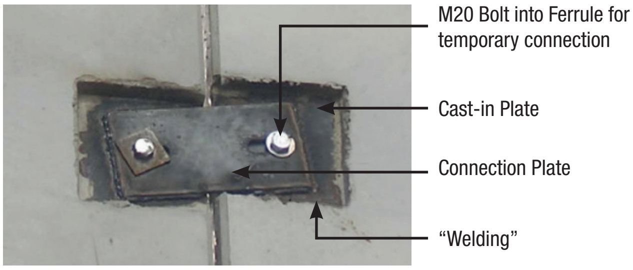

Figure 2 cast in plate in finished construction

Cast-in plates have been the go-to solution for connecting precast concrete panels since the inception of tilt-up and precast concrete construction. They can be used in a variety of connections from planar panel to panel connections to corner connections, floor to wall connections and steel beam to wall connections.

For a planar panel to panel connection they offer good tolerance for misalignment in the planar directions and can apply a significant force to address misalignment out of the plane by the tightening of the M20 bolts used to temporarily connect the joiner plate to the two plates. Once the joiner plate is attached, it is then welded in place to the two cast in plates via a fillet weld all way round the joiner plate and the M20 bolts are removed prior to grouting over the joint.

For connection of steel roof beams to precast panels, a steel cleat bolted to the beam is welded to the cast in plate while a crane holds the beam in position.

Cast in plates can offer the highest load capacity of all the options available to the design engineer and for panel to panel connections, potentially far more than is needed. This capacity comes with complete rigidity, which unfortunately often results in cracking around the joint due to thermal expansion and contraction of the concrete panels.

Aesthetically, cast in plates are perhaps the ugliest of joint options available as the joiner plates is most often at some angle and the welding due to the difficult positions can be unsightly even though perfectly structural. Therefore, cast in plate joints are generally recessed below the faces of the concrete panels to allow them to be grouted over afterwards.

The welding process of the cast in plates is the biggest hurdle to these joints, requiring qualified welders to be working at height. Such elevated hot work requires an exclusion zone around the joint to protect other construction personnel from the sparks and hot slag falling during the welding process.

The welding is a slow process, often exacerbated by the fact that the cast in plates are commonly hot-dip galvanized, requiring grinding of all the zinc from the faces of the plates and edges of the joiner before welding. For this reason, along with the considerable amount of welding required for each joint, a good welder may only complete 12-13 joints per day. It then requires a follow up crew to come through, cold galvanize paint the plates and joiner if they were galvanized and grout over the joints in an attempt to improve the aesthetics. This grout however has very little to bond to other than the flat faces of the steel and hence often cracks or separates from the concrete or steel.

The cost of a completed planar cast in plate joint (the simplest of the cast in plate joint) is in excess of A$300, with the precast yard covering perhaps 10% of this for the two plates (which are most often locally manufactured), and the builder then pays for the joiner plate, bolts, labour, touch up paint and grout.

Cast in toothed channel

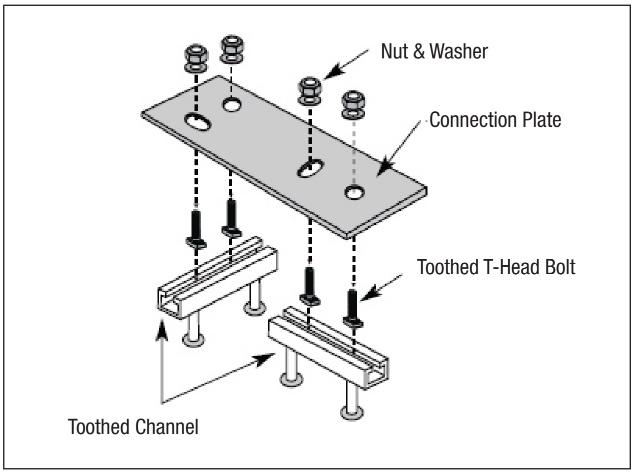

Figure 3 cast in toothed channel components

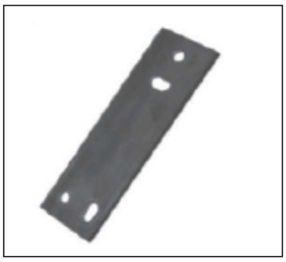

Figure 4 connection plate

Figure 5 connection plate being installed

Figure 6 cast in toothed channel in finished construction

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A cast in toothed channel joint comprises of two 175mm lengths of galvanized 38/17 toothed channel, 4 matching M16 toothed T bolt sets and a galvanized joining plate. The channel is cast into the precast panels typically recessed under the surface so that the joints can be grouted over.

This system offers considerable tolerance for misalignment (75mm vertical and 50mm horizontally) and by tightening the two M16 T bolts on either side will provide an equivalent force to a cast in plate joint to address misalignment out of plane. It is quick and easy to connect the two panels, requires no hot work and the hot-dip galvanizing of the channel and joiner remains intact providing excellent corrosion protection.

The joiner plate features a drilled hole and milled slot on each side, the milled slots being at right angles to each other. This allows for small errors in the alignment of the channels relative to the edges of the panels.

This joint is not as rigid as cast in plates as the milled slots allow some vertical movement and the load capacity is therefore limited to fiction in this direction until the bolts in the slots go into shear.

Typically, the joint will be grouted over after assembly, and this can often be completed by the same team saving time over the equivalent cast in plate joint. The grout will however be prone to the same problems with adhesion and cracking as with the cast in plate joints, but due to the smaller plate may be to a much lesser degree.

The cost of a completed joint may be around 60-70% of the cost of an equivalent cast in plate joint, with the precast supplier responsible for the cost of the channels and the extra work to fit them into the panels.

Cast in Ferules, oversize washers and fish plate

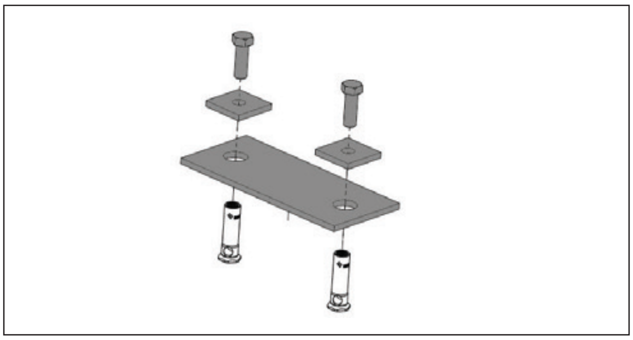

Figure 7 cast in ferrules, oversize washers and fish plate

Figure 6 cast in toothed channel in finished construction

One alternative is to use a joiner plate between cast in ferrules in the two panels. The joiner plate will need oversize holes (generally 40mm for M20 bolts) and then utilize very oversize washers on the bolts. This offers a fraction of the tolerance specified in AS 3850.2:2015 (1) being typically just +/- 10mm.

Where in plane shear is required, the oversize washers will need to be welded to the joiner plate, otherwise the shear capacity will be limited to the friction between the washers as defined in AS 4100:2020 Steel structures (5) for a friction Grip joint.

The capacity of this joint is limited by that of the cast in ferrules. Given this is a bolted joint it will not cause cracking due to thermal expansion and contraction that can happen with welded cast in plates.

This joint may be surface mounted, or recessed and patched over to improve the aesthetics, however, unlike the cast in plate joint, the hex bolts cannot be removed so the recess needs to be deeper.

Corrosion protection if no welding is done is excellent if all components are hot-dip galvanized, however like the cast in plate joint, this is compromised if welding is needed.

The cost of the completed joint is less than that for an equivalent cast in plate joint (perhaps 70%) with the precast yard needing only to supply M20 ferrules which will be a high volume component they have on hand, making up less than 5% of the total cost.

Post-installed anchors

Figure 9 Heavy duty chemical anchor

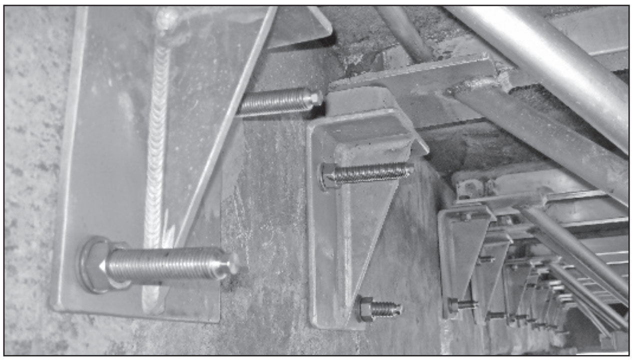

Figure 10 Heavy duty anchors in finished construction

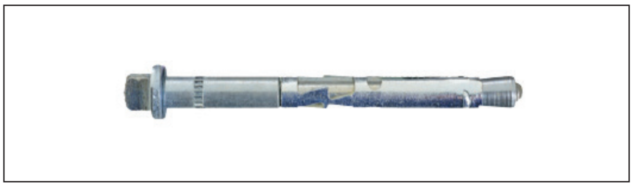

Figure 11 Heavy duty mechanical expansion anchors

Depending on the type of anchor and the spacing and edge distance available they can have a high load capacity, although there can be placement restrictions as the operative will need to avoid drilling through the concrete reinforcement. An aesthetic connection is achievable due to the different types of bolt finish available. Safety critical anchoring connections should be designed in compliance with AS 5216:2018 Design of post-installed and cast-in fastenings in concrete (6).

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Anchors are available in both chemical and mechanical options and in Hot-dip galvanized to AS/NZS 4680:2006 (7) and stainless-steel finishes for corrosion resistance and extended service life. Chemical anchors put less compression forces into the substrate since such forces only result from the applied load and this means spacing and edge distance constraints are less onerous, however, they do require curing time. Mechanical anchors can be loaded immediately but tightening torques put additional forces into the substrate and therefore is a greater sensitivity to spacing and edge distances.

Both types of anchors require time for drilling and hole cleaning, and this added to the curing time for chemical anchors has implications on costs for labour and crane time, and on safety if working at height. Some of these timing issues can be addressed by the use of drilling templates.

Costs for the anchors themselves vary on the type used, but typically the cost per kilonewton is similar across product ranges. The costs will fall to the main contractor rather than the precast fabricator and might be 50% cost of cast in joint plus the additional crane time.

Orbital Plate Washer Assembly

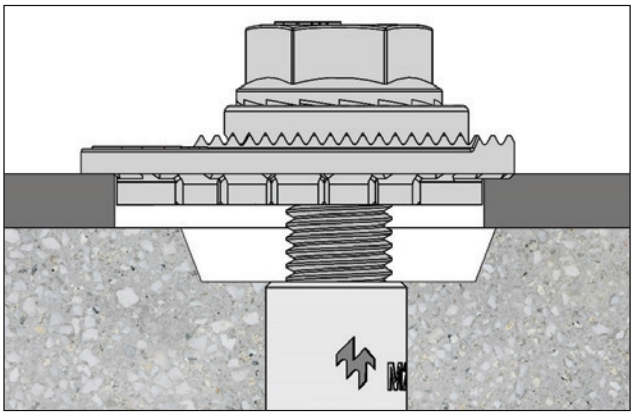

Figure 12 Orbital plate washer assembled

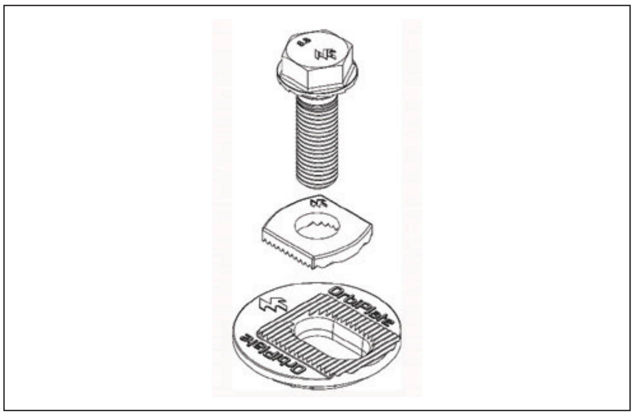

Figure 13 Orbital plate washer system components

The development of an orbital plate washer system by Australian engineer John Burke in recent years has allowed for the maximum 20mm tolerance in AS 3850.2: 2015 (1) to be taken up with a simple mechanical connection.

An 80mm circular washer with an elongated slot can be rotated in a 70mm hole in the steel component until the slot aligns with the ferrule. Calculations have shown that the large diameter results in a very small bearing stress and therefore no tearing will occur. Teeth on the underside of this washer engage with the fixture plate providing a locking mechanism that increases with the shear load eliminating slip.

The main washer has a serrated section on top which matches to serrations on the underside of second washer. The interlocking washers fit together in multiple positions to bring quick alignment between the structural grade bolt and the matching footed precast ferrule whilst delivering full shear connection. Serrations on the underside of the bolt flange provide slip resistance after installation and full bearing across the washer.

The components are hot-dip galvanized to AS/NZS 4680:2006 (7) for corrosion resistance maximising design life. There are neat and clean aesthetics in the type of joint because the joining plate can be adjusted to be level across the joint and as such there is no need to cover the joint, so no post-grouting is required.

A purely mechanical system such as this results in no hot works on the site to achieve the shear capacity and alignment and this results in good safety outcomes and lower costs. Being able to achieve the required alignment quickly and simply significantly reduces both labour time and crane time which are a large proportion of site costs. It also significantly minimises the overall construction time of the project. Safety is improved by negating hot works and by reducing the time worked at height. And because this is not a rigid welded connection, cracking around the joint due to thermal expansion is prevented.

This is the only methodology that allows millimetre precision and adjustability both at the time of installation and subsequently if required. This system would represent 25% of the cost of the cast-in plate joint with the precast company only supplying the 2 ferrules.

Conclusion

There are a number of methods used commonly on sites to achieve alignment within the allowable tolerance given in AS 3850:2015 (1). Choosing the correct connection for your project will be a balance between structural requirements, design life as determined under AS/NZS 2312.1&2: 2014 (3), erection time, project construction time, hot works allowance, and costs for the precast fabricator and the builder.

Methodologies that reduce construction time and costs will become the focus more and more as the pace of construction increases.

Acknowledgements

John Burke of Burke Engineering Services Pty Ltd

References

1. AS 3850:2015 Prefabricated concrete elements
2. ABCB, Durability in Buildings including Plumbing Installations 2015 second edition Handbook
3. AS/NZS 2312.1&2: 2014 Guide to the protection of structural steel against atmospheric corrosion by the use of protective coatings
4. AS/NZS 3750.15 Paints for steel structures Inorganic zinc silicate paint (Reconfirmed 2013)
5. AS 4100:2020 Steel structures
6. AS 5216:2018 Design of post-installed and cast-in fastenings in concrete
7. AS/NZS 4680:2006 Hot-dip galvanized (zinc) coatings on fabricated ferrous articles
8. Ramset™ Specifiers Anchoring Resource Book ANZ Edition 2 Revision 1 2019
9. Reid™ OrbiPlate™ Design Guide AU & NZ July 2020

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