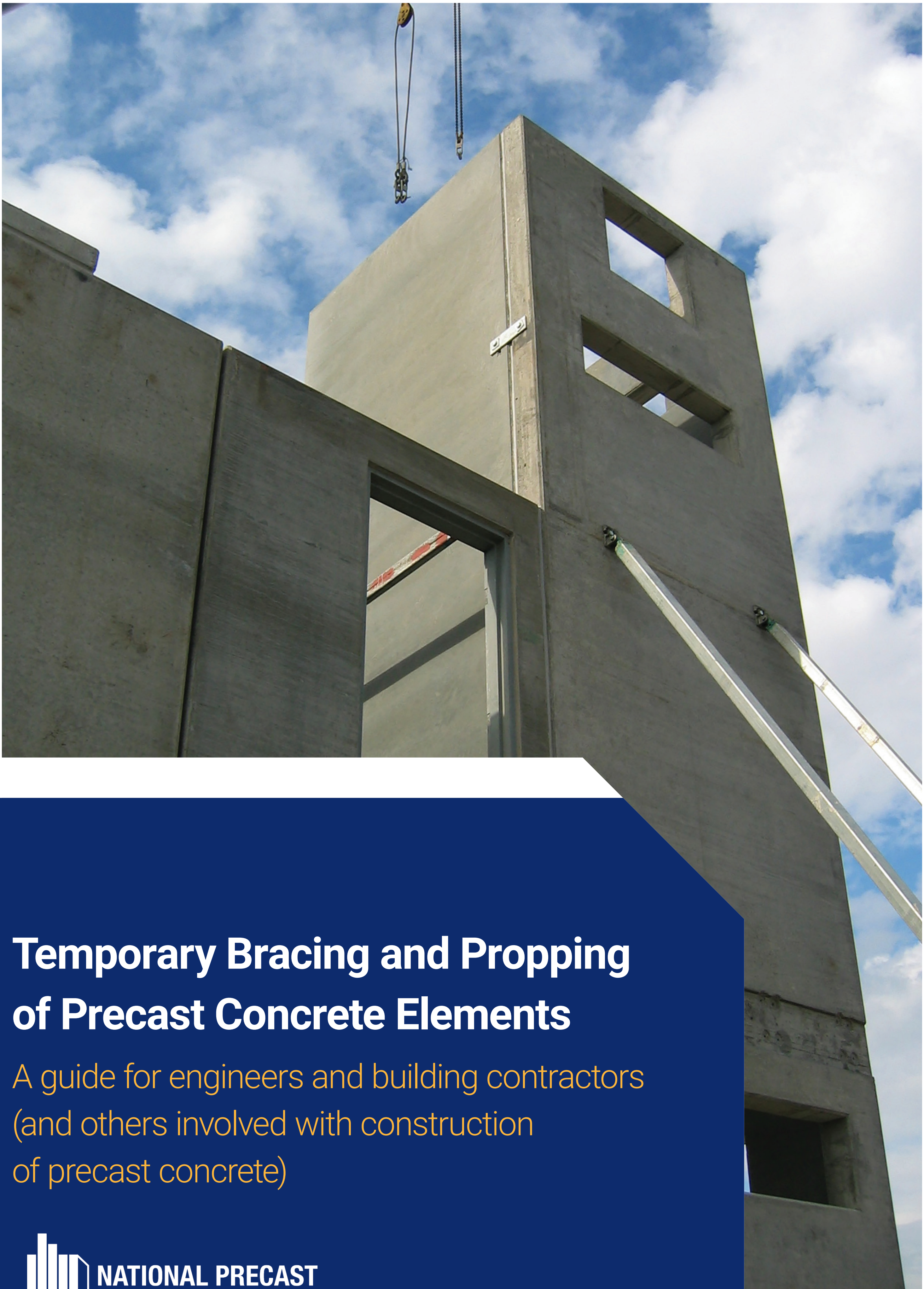

Temporary Bracing and Propping of Precast Concrete Elements

A guide for engineers and building contractors (and others involved with construction of precast concrete)

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CONCRETE ASSOCIATION AUSTRALIA

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1 Introduction

Temporary bracing and propping are methods of securing structural prefabricated concrete (also referred to as precast concrete) elements during the construction phase until they are permanently supported by, and incorporated into, the adjoining completed structure. Typically, bracing is applied to vertical elements and propping to horizontal elements.

This Guide considers the responsibilities, requirements, specifications and use of temporary bracing and propping for prefabricated concrete construction, as it relates to **factory-cast** concrete elements during their construction phase. The engineering principles involved for safe lifting, handling and temporary bracing, however, are applicable to all forms of prefabricated building and civil elements and structural systems.

The Guide is intended for the ‘competent persons’ that participate in construction involving prefabricated concrete (as referred to in relevant Australian Standards and State and Territory Codes of Practice), namely:

- project managers;
- architects;
- engineers (including In-service and Erection Designers);
- builders/head contractors (and for those under their control); and
- installers.

In addition to various Australian Standards (AS) and relevant State and Territory Codes of Practice (which support Workplace Health and Safety (WHS) Regulations), users also need to be familiar with, and comply with, guidance from the relevant Workplace Safety regulator. Several external sources of guidance are referred to in Section 6 of this Guide, *References and Further Guidance.*

Prefabricated concrete construction is commonly classified as a high-risk activity, and therefore has even more requirements concerning temporary support than some other forms of temporary works.

As construction complexity increases, so too does the benefit of peer-reviewed risk management, in order to achieve best practice. Accordingly, all involved persons should document their input to easily enable an independent party to check and validate the decisions and actions taken, as part of a peer review or investigation.

When it goes wrong

Unfortunately, and although very rare, failures of bracing and propping systems have occurred. Damage from failure can be significant and the possibility of injury or loss of life is real. It is the possible consequence of what can go wrong that must always be considered while undertaking the temporary works design.

This Guide does not cover cranage, lifting of precast elements or the design of chains and slings. Refer to National Precast's Precast Concrete Handbook and AS 3850 for guidance on handling.

2 Terminology and Componentry

For definitions of terminology used in this Guide, refer to current editions of AS 1170, AS 3600, AS 3610 and AS 3850. Note that references to 'fasteners' in this Guide also include anchors, expansion anchors/fixings and similar (refer to AS 3600 and AS 5216). The words 'loads' and 'actions' are interchangeable in this Guide.

The predominant two terms used in this Guide are 'bracing' and 'propping', and so it is important to understand the differences between the two.

Bracing (see Figure 1) is an engineering term for the structural components that resist and transfer lateral (horizontal) loads imposed on a structure. Typically, bracing applies to the securing of vertical elements, usually down to the footing system. Usual sources for these loads are wind, gravity induced/out-of-plumb forces, seismic effects and construction loads. Resistance of such loads is required in the temporary and permanent stages, and in the temporary stage, this is typically achieved using inclined braces.

Propping (see Figure 2) is an engineering term for the structural components that resist and transfer vertical loads (usually self-weight and construction loads), typically for horizontal elements. The term is usually applied in the case of temporary supports only. Any lateral loads that exist with horizontal elements would usually be resisted by bracing.

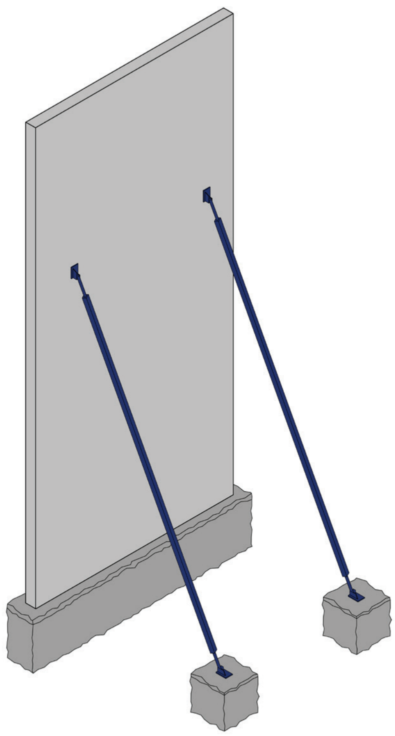

Figure 1 – Bracing of precast panel

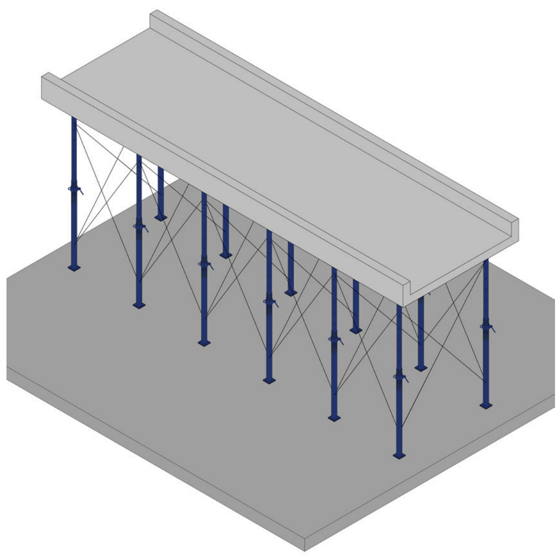

Figure 2 – Propping of precast floor (with diagonal bracing)

Also refer to Figures 3 to 7 below, depicting various components related to bracing and propping.

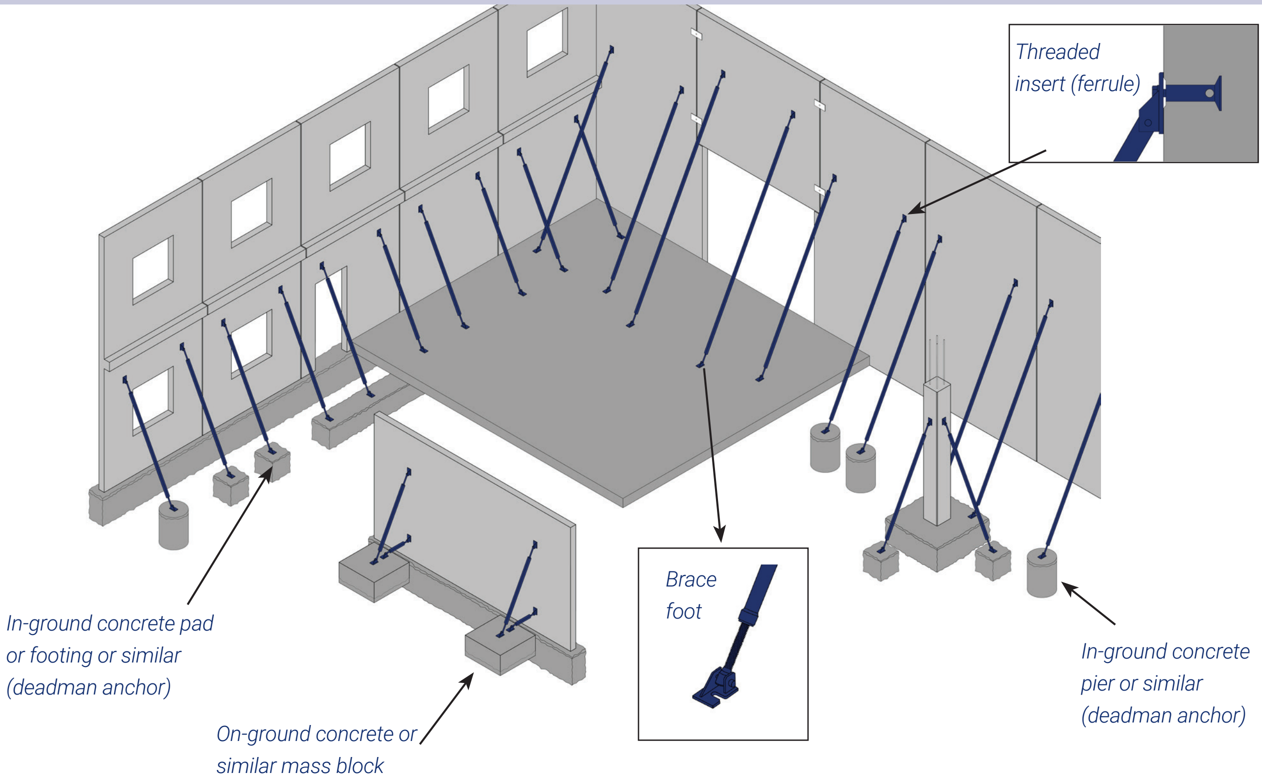

Figure 3 – Typical components used in bracing and propping

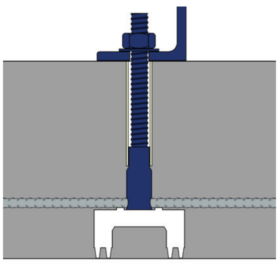

Figure 4 – Brace foot connection utilising a deep threaded insert for large effective embedment

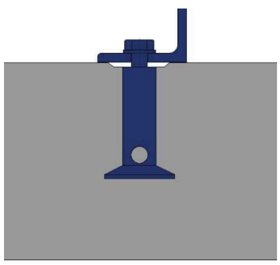

Figure 5 – Brace foot connection utilising a threaded insert

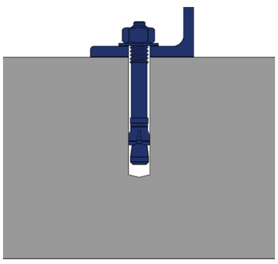

Figure 6 – Brace foot connection utilising a post-installed mechanical anchor

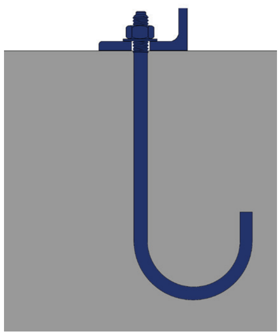

Figure 7 – Brace foot connection utilising a J-Bolt (requires deeper concrete embedment)

3 Design and Specification

Much of this chapter principally relates to the bracing of precast elements.

3.1 Responsibilities

AS 3850:2015 Prefabricated concrete elements introduced and defined the concepts of an **In-service Designer** and an **Erection Designer** (also referred to as an Erection Design Engineer or an EDE).

AS 3600 Concrete structures refers to AS 3850, and is referenced by the National Construction Code (NCC). This means that the requirements for an Erection Designer are now embedded within the national building regulations for buildings.

The Victorian Industry Standard (the Blue Book) and other State or Territory based Codes of Practice or industry standards for buildings, may similarly define the Erection Designer and In-service Designer and detail their responsibilities.

The regulatory environment applicable to the project may also require various involved parties to be licensed or registered (e.g., as a builder or engineer). Contract documents cannot ignore the use of such competent persons or regulated professionals who are required to be compliant and consistent with existing WHS regulations.

It is important that the contract documentation sets out who is responsible for employing the Erection Designer.

For example, a precast concrete manufacturer may offer supply only and provide 'truck on site' (or 'FOT'/'free on truck'), and the Erection Design may be the responsibility of the builder or head contractor. In such an instance, the Erection Designer will typically be employed by the head contractor. The responsibility for employing the Erection Designer needs to be clearly defined in the project contract documentation. Noting that the precast concrete manufacturer is responsible for handling in the factory, they may also be responsible for checking the initial lifting off the truck on site (particularly the rotation from horizontal to vertical), in which case the manufacturer may also employ an Erection Designer.

On many projects, external engineers - such as engineers employed by component suppliers - may offer designs and provide certification for the temporary bracing and propping of precast elements, as well as their lifting and handling. It should be understood that while this work must be completed by a suitably qualified (and insured) engineer, this is only part of the responsibility of the project Erection Designer and does not relieve the Erection Designer of their overall responsibility.

Other considerations for the Erection Designer (using engineering principles and appropriate design standards for bracing) include:

- The design of the connections at both ends of the temporary braces;
- The selection of the correct bracing and the specification of the anchors;
- The anchor conditions (into an existing concrete structure or dedicated footings);
- Any factors and forces that may impact on the element once braced or propped (for example, wind loads on the cantilevered portion of an erected vertical panel above the brace ends) to ensure the structural design of temporary braces and props, and their required connections, not only supports the elements, but also enables the elements to behave structurally; and
- Overall temporary stability of the structure.

Image 1 – Complicated arrangement of elements require the Erection Designer to provide detailed guidance as to what is required during construction

Where the manufacture drawings and details (or Marking Plans, Elevations and Shop Drawings) for the prefabricated elements are assigned or subcontracted to others - for example, to the precast manufacturer - this does not relieve the Erection Designer of their responsibilities.

It is during this stage in which much of the co-ordination of the Erection Design Documentation commonly revolves, i.e. lifting design of the precast element (incorporating concrete strength at lifting, reinforcement, lifting inserts, strong-backs and rigging details - noting these should be specified and included on Shop Drawings) and bracing/propping design (incorporating concrete strength at erection, componentry required for connection, and bracing and/or propping diagrams, etc). Once completed, these drawings must then be reviewed and approved by the Erection Designer, as well as the In-service Designer.

The Erection Designer may be also involved in provisions for cranage, safe lifting and handling.

Where possible, the In-service Designer should discuss the proposed erection with the contractors before design and documentation to ensure the feasibility and practicality of the in-service design. It should be noted that the In-service Designer has a duty to have considered, and make any provision for, at least one safe method of construction.

However, where the prefabricated concrete is unusual or complicated, then it is the responsibility of the structure's In-service Designer to provide detailed guidance in the contract documents as to what is required during construction.

3.2 In-service Designer, Erection Designer, builder and contractor responsibilities: construction

The builder (or head contractor) is responsible for all activities on their site and the safe construction of all specified details, which is not limited to compliance with WHS provisions. The applicable Workplace Safety regulator for the project can give further guidance.

These responsibilities include any subsequent inspection and maintenance of installed temporary works (including temporary bracing and propping). Refer to AS 3850, AS 3610, and State and Territory requirements, such as the Victorian Blue Book.

The Erection Designer is responsible for ensuring that post-installation inspections are conducted weekly and after major weather events, to ensure temporary braces or props and their connections are secure. Related guidance may be found in the AS 3850 series of standards.

Regarding the use of proprietary structural products (e.g. telescopic braces or bolted connection systems into concrete) it is the responsibility of the product supplier - as part of their required instructions for safe use - to address any inspection or maintenance processes for the service life of their product. Refer to Section 7.1 for sample wording regarding the inspection of a torque controlled expansion anchor, which a supplier may endorse.

There have been examples of worn, damaged, bent or corroded braces and props being used on-site. It is important that these critical pieces or temporary works equipment are correctly maintained and serviced to ensure they are able to perform as intended, and as specified in AS 3850.

3.3 Engineering design and practicalities

The purpose of any engineering design is to account for the known and reasonably predictable factors in any physical system and to predict and to manage all practical behaviours and actual performance.

Where the potential for personal injury and/or material or property damage is present, then the designer's duty to control related risks is often subject to regulation. As with other activities, engineering design should ONLY be undertaken by those who are competent in that required engineering design, as is evidenced by relevant training, qualifications and experience.

In the case of temporary bracing design for precast concrete elements, the structural environment typically involves lateral - or horizontal - forces (such as wind), tending to cause overturning or sliding. Similarly, propping design considers weight or gravity-induced (vertical) forces, tending to cause displacement downwards and/or bearing failure of supports (refer to Figures 8, 9, 12, and 13).

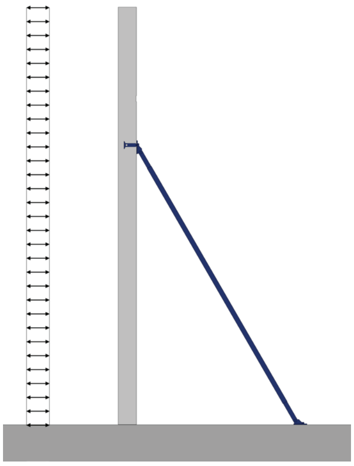

Figure 8 – Braced panel with typical loading

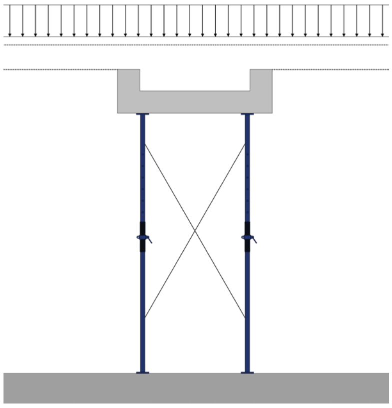

Figure 9 – Propped precast element with typical loading

Bracing and propping design

Although in-service (or permanent works) design is carried out using Limit State Design methods, temporary bracing and propping design is carried out using Working Stress Design methods.

AS 3850.1 (Section 2.2) refers to this and notes that proprietary structural systems (e.g., temporary braces and brace anchor bolts) are typically rated to a Working Load Limit (WLL).

At all times, the design process and analysis should be guided by competent engineering judgement. This should use Australian Standards which set out the minimum requirements for factors or loads to be adopted, particularly concerning overall stability against overturning, sliding and progressive collapse.

The most common and typically governing source of lateral forces that requires temporary bracing in the construction phase for precast elements, is wind.

The principal design guidance regarding wind is found in AS 1170 Structural design actions and in the AS 3850 series.

Tables F1 and F2 in AS 1170.0 indicate that bracing and propping - as construction equipment - should be designed for Importance Level 2, and a regional wind speed based on V_{100} but with provisos. Refer also to AS 3610.1 Formwork for concrete for guidance on propping and falsework.

A design procedure for determining wind loads is given in AS 3850.2 (also refer to AS 1170.2). An engineer competent in bracing design will have appropriate experience with these requirements, but some comments are made within this Guide regarding precast elements (refer AS 1170.0, AS 1170.2, and AS 3850.2).

Refer to Section 7. Appendix for specific design and documentation guidance for temporary bracing and propping.

Image 2 – Element bracing design should resist common lateral forces such as wind

4 Temporary Support of Precast Elements

The extent to which a precast element requires temporary bracing and/or propping during the construction phase depends upon the component geometry and forces involved.

Precast wall and column elements typically require temporary bracing and usually no propping.

Precast floor and beam elements - if not able to be supported initially on their permanent support - may require temporary propping and no temporary bracing. If multiple props are used, then they may need to be braced.

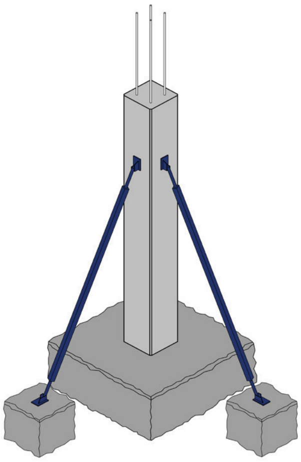

Figure 10 – Braced column

Image 3 – Braced precast columns

Image 4 – Temporary propping of precast shell beams, (supporting hollowcore flooring) during construction

Some precast elements, such as precast traffic barriers, typically require neither bracing nor propping, although the surface supporting them may need attention so as to improve sliding resistance or restraint.

Regardless of the application, each case must be assessed for the forces involved, and how these forces must be resisted. This question of reliability and progressive collapse underscores the requirement for temporary bracing and propping.

Braces and props should never be supported by other braces and props, nor by temporarily braced or propped precast elements, unless carefully considered by the Erection Designer (in which case it should be clearly detailed in the Erection Design Documentation).

Considerations that are critical to the safe temporary bracing and propping of prefabricated concrete elements, include (but are not limited to):

- All specified structural support systems must be engineered and approved by the Erection Designer as part of the Erection Design Documentation;

- All relevant shop drawings must be reviewed and approved;

- Relevant engineering and architectural drawings should be reviewed;

- A complete temporary works design (bracing and propping) which is specific to each precast element, must nominate the type and location of braces, their support conditions and required connections, including bracing inserts, anchors and footings. This is more extensive if secondary bracing has also been specified, which may include double knee braces, or horizontally interconnected single knee braces plus diagonal end braces. See Section 4.4.2 Figures 15 and 16 - Typical components used in bracing and propping;

- The use and correct installation of rated and marked bracing/propping systems must be verified by the precast manufacturer (including any cast-in items), and by the erection/installation contractor on site before being loaded;

- Any changes to the above requirements (including moving or removal of braces or props before final removal) must be reviewed and approved in writing by the Erection Designer; and

- Site inspections are carried out as required, noting the minimum requirements as set out in AS 3850

Erecting precast on steel beams

Care should be taken when erecting prefabricated concrete elements on steel beams. Steel beams will often not have sufficient lateral rotational capacity to support precast during construction, particularly when using web cleats at each end, and may twist. The steel beams are also more susceptible to progressive deflections as the precast is installed, making the alignment and levelling very difficult unless the beam is very stiff.

In all instances, design should be carried out by an appropriately skilled and experienced person.

While the Erection Designer is responsible for all of the temporary works during construction, in certain circumstances, it is not uncommon to use specialists to assist with the Erection Design Documentation.

Any delegation of tasks however, should be clearly noted in the Erection Design Documentation by the Erection Designer. In fact, this is common practice in the industry.

Common examples where the Erection Designer may seek input from others are with formwork design and the temporary support of precast elements that are supported by steel beams, such as balcony units and spandrels.

Image 5 – Prefabricated floor units installed on permanent steelwork

4.1 Bracing of vertical precast elements

In situations where the existing structure cannot be used for support (or is not adequate) and a temporary footing is required, the Erection Design will require geotechnical site information to evaluate the allowable ground-bearing pressures and lateral resistance, and the design and documentation of a temporary footing.

The following are the basic principles involved in the bracing of vertical precast concrete elements:

- Two braces are always preferred;
- For long or tall single-storey panels, three or more braces may be needed for practical reasons (note that with more than two braces per panel, some analysis of load sharing will be required;
- The top of the brace generally connects to an M20 threaded insert (ferrule) which has been cast into the face of the precast element, with an M20 bolt (Class 4.6); and
- The base fixing - which is often a post-installed anchor - commonly has a head size of an M20 bolt (30mm AF), a shank size (shear section) of an M16 bolt and an M14 thread size (high tensile) with a structural washer. These fixings, including required capacity, must be checked by the Erection Designer.

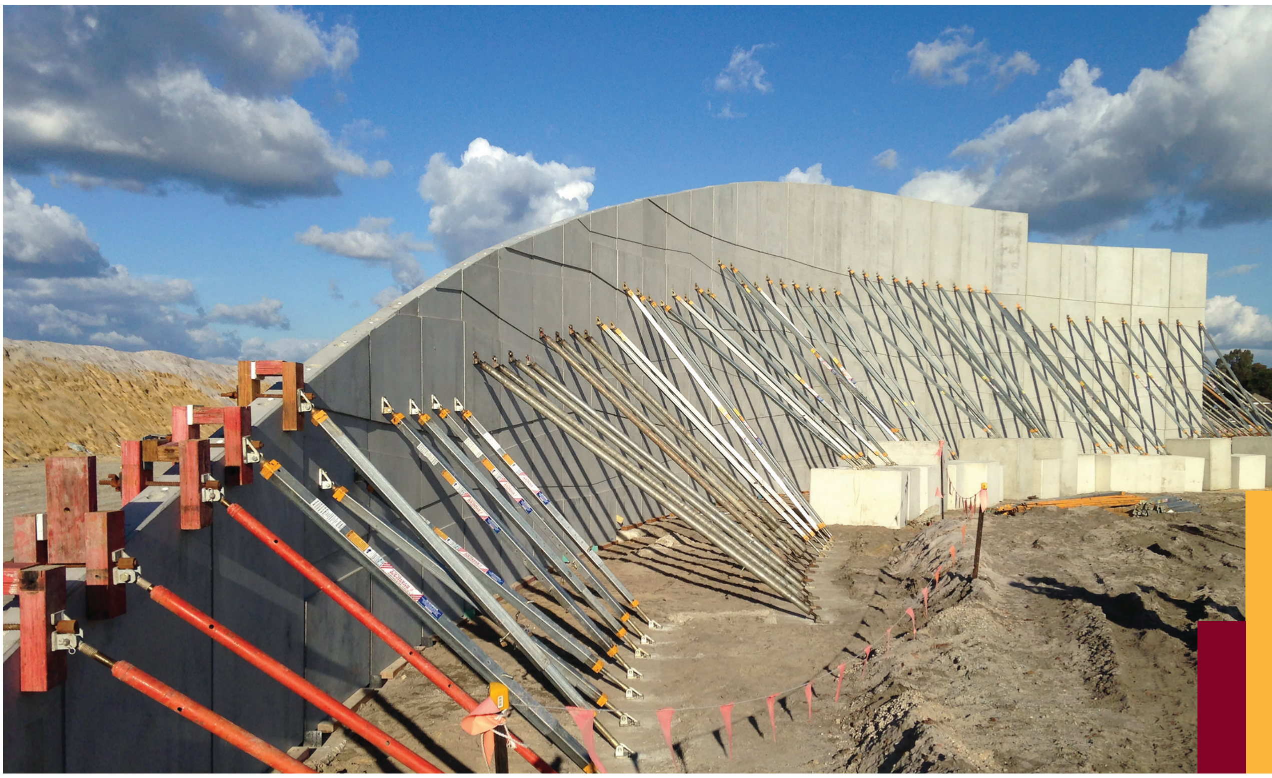

Image 6 – Bracing of a retaining wall utilising dead man footings as well as mass concrete blocks

Technical data relating to the specific mechanical fixing capacity and performance should be provided by the anchor supplier. Each of the manufacturers have specific requirements for combining loads and edge distances, and the Erection Designer will need to check the various load combinations depending on the chosen fixing (AS 3850 provides the formula for brace anchor design as $[N_s / (R_{u,N}/F)]^{1.5} + [V_s /(R_{u,V}/F)]^{1.5} \leq 1.0$);
Where

$R_{u,N}$ = characteristic ultimate tensile strength of cast-in insert

$R_{u,V}$ = characteristic ultimate shear strength of cast-in insert

N_s = tension component of the applied load

V_s = shear component of the applied load

- The base of a precast concrete element must have adequate lateral resistance by a direct shear connection when placed in its temporary condition. Friction cannot be relied upon, as it can be highly variable and is not allowed by AS 3850; and

- Deformation controlled expansion anchors - including self-drilling anchors, concrete screws, drop-in and spring coil anchors - are not permitted for use as post-installed brace fixings.

Image 7 – Top brace connection utilising a threaded insert and an M20 class 4.6 bolt

Image 8 – Bracing of multi-level prefabricated concrete elements

Erecting vertical precast elements on post-tensioned floors

When vertical precast concrete elements are erected on post-tensioned concrete floors (which are subsequently stressed), allowance should be made for the relative movement of the floor in relation to the final position of the vertical element.

Image 9 – Precast stair shaft braced on opposite sides

Bracing inserts should be installed in the prefabricated concrete element with a tolerance that should not exceed 50mm (see AS 3850.2). The brace angle should not deviate more than 5 degrees from the specified angle. Figure 11 shows the typical tolerances for the brace installation.

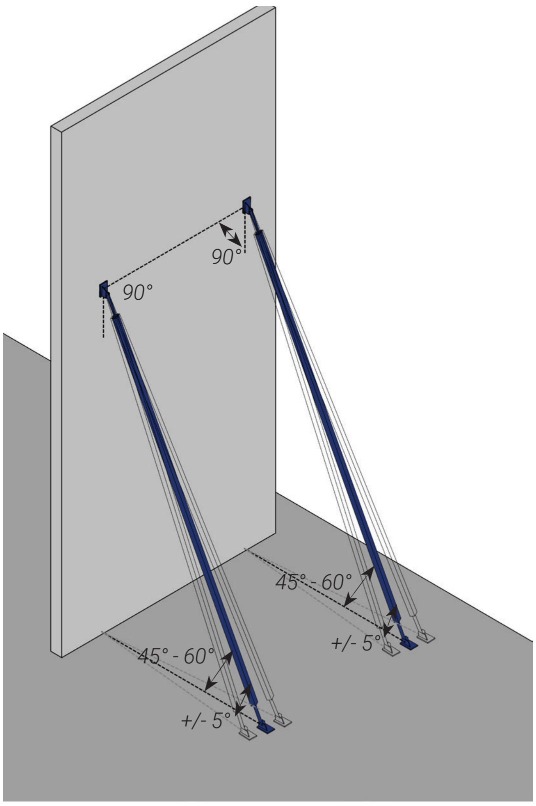

Figure 11 – Braced panel with acceptable tolerances

Durability of inserts and bracing components

It is recommended that all bracing inserts should have the same corrosion protection to satisfy the minimum durability requirements of AS 3600, and to reduce confusion during the manufacturing process if zinc-plated or hot-dip galvanised are specified.

In exposed areas where durability is a significant requirement, bracing inserts will be required to be galvanised or stainless steel.

Where exposed to view, ferrules may be set back a minimum distance (for example, 10mm) from the face of the concrete to allow local patching. In such instances, a suitable length bolt will need to be specified and the bolt bending that results from the additional lever arm which needs to be applied to the shear force, needs to be considered in the design.

Where the concrete finish is not painted, is left exposed and is visible to view, then the local patching should match the colour of the surrounding concrete.

4.2 Propping of horizontal precast elements

Many precast concrete elements are erected directly onto preceding construction, such as a slab, which supports the element weight and additional construction loads (including a construction live load allowance) and provides stability.

When precast elements are unable to span on their own - such as composite precast elements and similar, or a wall panel with a large opening across the base - propping will be required, until the required associated structure (such as in-situ concrete), is complete. This support may be comprised of one or more individual props, or an array of interconnected and braced props, forming a scaffold (termed falsework or shoring). Refer to AS 1576 and AS 3610.

Although the vertical loads may dominate, a horizontal component to withstand a portion of the vertical force is required (refer to AS 3610). Should there be any staging in the application of loads, then the propping design should account for all stages of loading, including the worst case.

Once the appropriate design actions (loads) are determined, then the engineering process to calculate prop loads (and specify the props, their braces and connections) is the same as that which calculates the resisting major lateral loads on main braces (e.g. from wind or construction).

The supporting design reactions for the props should be considered in the design of the adjoining structure, that is, supporting the props and braces.

As with the bracing for lateral loads, such as wind, there are many proprietary propping systems available.

Where the propping design is completed by a specialist in this area (for example, a formwork designer from a formwork company), the design must be completed by a suitably qualified (and insured) engineer. This design should be submitted to the project's Erection Designer for approval and does not relieve the Erection Designer from their overall responsibility.

Image 10 – Precast flooring may require propping when the elements are unable to clear span on their own,, especially if a composite topping slab is added

Critical considerations for the safe propping of horizontal precast elements

- All propping systems must be engineered and approved by the Erection Designer as part of the Erection Design.
- The Erection Design Documentation, including a review of all relevant shop drawings, must be provided and be available on-site, **prior** to erection commencing.
- Rated and marked propping systems must be specified by the Erection Designer and in the Erection Design Documentation, then correctly installed by the erection/installation contractor and verified by the builder/head-contractor on completion.
- A complete propping design is specific to each precast element and nominates the type and set out of all propping components, their support conditions and required connections. This must include sketches, drawings, notes and the like, so that the erection/installation contractor and builder/head contractor understand the requirements, particularly when both bracing and propping may be required.
- Changes to any of the above requirements (including moving or removal of frames or props before final removal) must be approved **in writing** by the Erection Designer.
- Props and frames should be vertical and should also be braced for lateral loads of the whole assembly and the buckling of individual props.
- Site inspections must be carried out in accordance with AS 3850.
- Precautions should be taken to provide a robust method of protection to props and frames, particularly from possible impact loads.
- Final removal of frames and props must be approved in writing by the In-service Designer.
- Extensive arrays of propping should also be designed to manage the risks from progressive collapse or disproportionate failure.

4.3 Design of bracing and propping

Until integrated into the overall structure - of which they are a part - each precast element, when erected, is to be considered as an independent structure, with the same requirements for safety, stability and strength in its use and function.

Overall stability analysis typically considers base shear connections to resist sliding, temporary braces to resist overturning, and bearing capacity to resist settling (deflections and serviceability).

Of these, component bracing usually requires the most attention and is typically governed by wind actions. Component propping typically addresses temporary vertical support only (i.e. resists deflection and serviceability requirements), although the propping system may also require temporary internal bracing to provide stability during construction.

Refer to AS 3610 and to Figures 12 and 13 for typical loads for braced and propped precast elements.

Designers should refer to AS 1170.2 Section 2 to determine the appropriate wind load on each precast element.

The temporary support for each precast element (typically wall panels) should be designed as an individual freestanding element (AS 1170.2), even if erected as part of a continuous wall. The resultant wind force should be applied to the centroid of the elevation area (which may not coincide with the centre of gravity of the element). The calculation of resisting forces in the temporary brace(s) and brace end anchorages may then be determined by simple statics.

These calculated actions can then be compared to the capacities for the brace and anchorage solutions being considered. If proprietary systems are being used, then the manufacturer or supplier of the system must provide capacity information, complying with AS 3850, to enable correct selection.

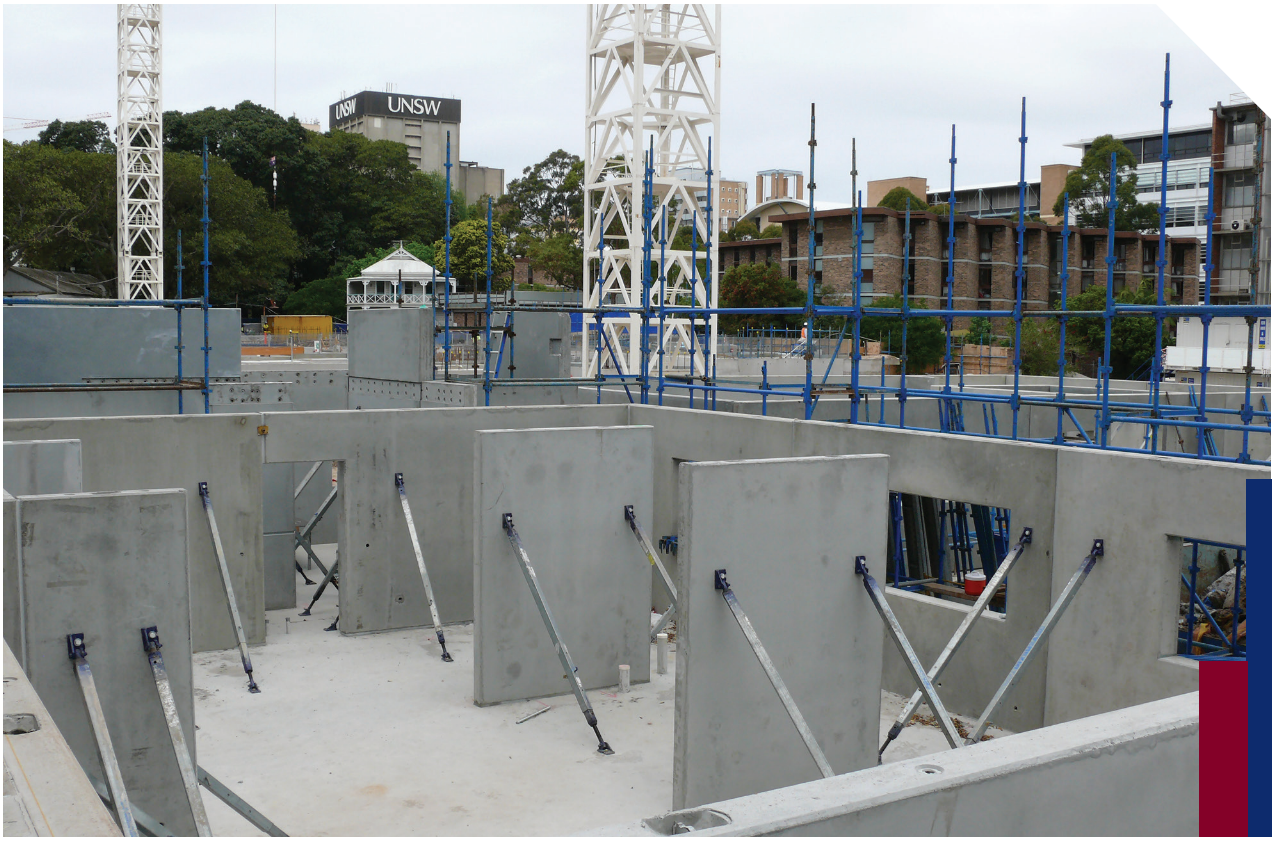

Image 11 – Braced prefabricated wall panels, where braces are typically attached at about two thirds of the panel height

Considering the general case for simple rectangular wall panels, temporary braces are commonly attached at about two-thirds of the panel height to minimise and balance the wind-induced maximum panel bending (this is a guide only), although it is rare for such bending stresses to be a problem.

Construction may dictate a different bracing height or location, which must be detailed within the Erection Design Documentation.

Temporary braces are typically inclined at an angle of between 45-60 degrees, although this is not a requirement. If steeper braces are used, the resultant loads increase. This must also be detailed in the Erection Design Documentation.

If braces are telescopic, they have increased buckling capacity. They also attract a greater load, particularly to the end anchorages.

Often the brace selection is constrained by the capacity of the end connections/anchorages and for taller panels, the length of braces available.

Where horizontal precast elements require temporary support during construction, they will be propped before incorporation into the surrounding structure.This mainly involves the support of the element's self-weight (plus any additional superimposed loads before integration, such as concrete screeds and construction loads) by an appropriate member, that acts as an axially compressed column.

Image 12 – Large prefabricated panel which is braced on two levels

Image 13 – Precast columns with temporary bracing to provide horizontal restraint

As with temporary braces, where proprietary system props are used, the prop supplier or manufacturer must provide capacity information complying with AS 3610 and AS 3850 to enable the correct selection or design by the formwork engineer. It is up to the Erection Designer to satisfy themselves that the information that has been provided will comply with good practice as well as with Australian Standards.

To prevent buckling of temporary props and braces, their compression capacity may be increased by introducing additional restraints or knee-braces. The Erection Designer should note that this cannot be achieved with only a single knee brace. Further guidance can be found in Section 4.4.2, on Figures 15 and 16, and in the AS 3850 series.

In all the above cases, the specified solution must be supported by the correct engineering analysis and must also account for all safety requirements and all relevant site conditions.

Image 14 - Knee-braces (affording restraint in all directions) may be used to increase compression capacity of telescopic braces

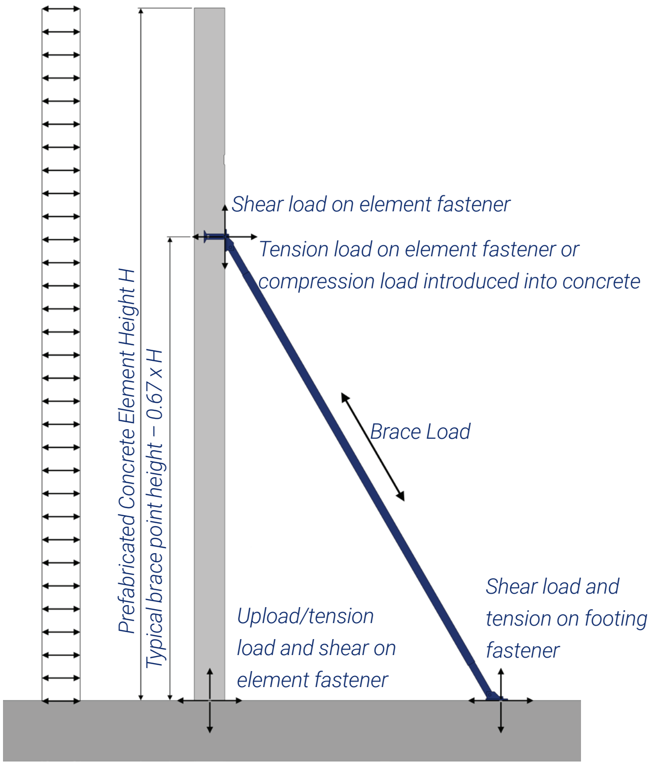

Figure 12 – Loading for braced precast wall panel

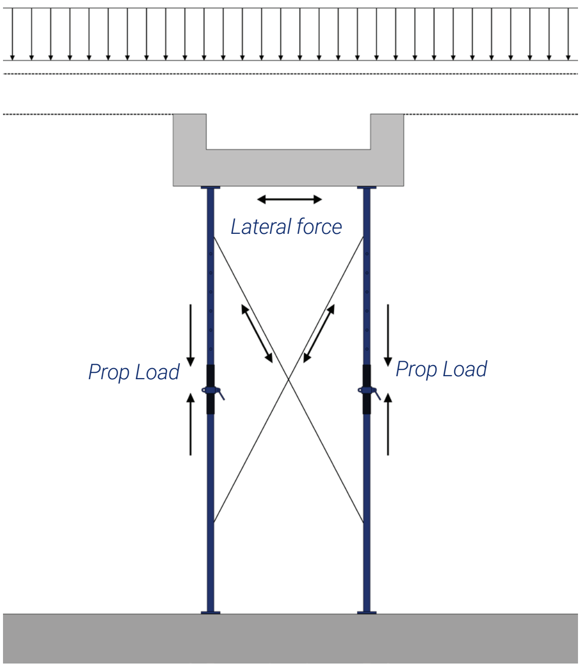

Figure 13 – Loading for propped precast element

4.4.1 Temporary brace/prop connections and anchorages

The structural connection of temporary braces and props to concrete generally involves the transfer of shear forces as well as tensile and compression forces for temporary braces. For such connections, the designer should consult AS 3850.

Further information regarding fastenings in concrete may be found in AS 5216, but note that AS 5216 excludes any fasteners for lifting, transport, erection and bracing.

Connection of the brace can be achieved by either cast-in threaded inserts, or post-installed anchors.

When designing cast-in brace inserts, the designer should consider following failure mechanisms, including:

a) Steel failure of the bolt in tension;

b) Steel failure of the bolt in shear;

c) Combined steel failure of the bolt;

d) Steel failure of the threaded insert in tension;

e) Concrete breakout failure in tension (concrete cone failure;

f) Concrete pull-out failure;

g) Concrete blow-out failure;

h) Concrete edge failure in shear (if installed close to an edge);

i) Concrete pry-out failure; and

j) Combined concrete failure.

Where proprietary post-installed anchors are used, the supplier must provide all necessary information for safe design, installation, in-service use, and the ongoing condition assessment for the system in accordance with the AS 3850 series.

Proprietary post-installed anchors should be installed, inspected, and verified in accordance with the supplier's technical information, and special attention should be paid to the correct drilling of holes and tightening to the specified installation torque (note: it is critical not to under-torque or over-torque). See Section 7.1.

The use of post-installed chemical anchors as brace fasteners is not recommended. If however, they are used, each anchor must be proof loaded on-site before use, in accordance with AS 3850.

There are limitations for expansion anchors regarding minimum concrete spacing and edge distances. Cast-in inserts are less sensitive to this, but edge distance and anchor spacing still need to be considered.

Class 8.8 bolts should not be used with cast-in threaded inserts, as, if they are over-torqued, the high torque capacity for Class 8.8 bolts can damage the threaded insert and pull out the surrounding concrete. Class 4.6 bolts should always be used, as - in the case of over-torquing - the bolt should fail and not the insert (refer to AS 3850.1).

A calibrated torque wrench should be used for the installation of bolts in threaded inserts and post-installed anchors, as specified by the manufacturer.

High-torque impact wrenches (often referred to as rattle guns) should not be used, unless fitted with an appropriate torque limiter.

Often, threaded inserts are installed with recesses, using nailing plates.

For recessed threaded inserts, shear loads will create bolt bending that needs to be considered and designed.

Deep recesses of the threaded insert should be avoided, to limit bolt bending.

Bolt lengths must also be carefully considered and specified.

Bolts that are too short may not reach their full capacity and can fail through thread stripping due to a lack of thread engagement.

Bolts that are too long can hit the end of the thread in the threaded insert before being fully engaged.

It is important that a recessed installation of the threaded insert needs to be accounted for when calculating the bolt length. The threaded insert manufacturer should specify the minimum engagement as well as the required bolt engagement length for the threaded inserts (AS 3850.1).

Any welding to bolts should be avoided. Welding to the threaded inserts is also not recommended as the material properties of the threaded insert may be affected. Grade 8.8 bolts and similar high-strength bolts or tendons should not be welded as they are a high tensile material and are likely to fail in brittle failure.

If welding is specified, a welding procedure specification must be developed to take into consideration both the design and materials being affected. All welding should be carried out by a certified welder.

For headed threaded inserts, the effective embedment depth is generally defined as the dimension from the top of the head to the concrete surface. Recessed installation of the threaded insert will increase the effective embedment depth, but will create bolt bending.

When calculating concrete capacities, the Erection Designer should consider the concrete strength at the time when the connection is made, which is typically a lower strength than the specified 28-day strength of the concrete.

This is particularly important for the connections of the brace foot to recently cast slabs, footings or similar, as these can have low concrete strengths at the time of installation.

Also, concrete poured with supplementary cementitious materials may have slower strength development in its early life that needs to be considered.

4.4.2 Temporary braces and props

Most temporary braces and props used in practice for prefabricated concrete construction are proprietary telescopic systems, typically with additional fine adjustment via a screw thread.

Temporary braces are typically manufactured, and behave as, pin-ended columns. Many props effectively behave the same way (even with light fixed end plates). Testing, load rating and inspection requirements are given in AS 3850.1 and AS 3610 respectively.

The Working Load Limit (WLL) of temporary braces and props is based on the axial capacity, which is the minimum of the buckling capacity of the brace/prop profile and the connection capacity.

The brace/prop loads (reactions) should be checked against the WLL stated by the manufacturer based on the specified brace/prop length required for the project.

Image 15 – Braces and props are generally proprietary telescopic systems

It should be noted that some brace manufacturers also specify the use of additional knee braces for longer length braces, and these require that the brace be laterally restrained in all directions, in accordance with the brace supplier/manufacturer's guidelines or as designed by the Erection Designer. Typical bracing and propping are shown in Figures 14, 15 and 16.

AS 3610 provides design guidance for the mid-point restraint and the force to be resisted by the knee brace arrangement.

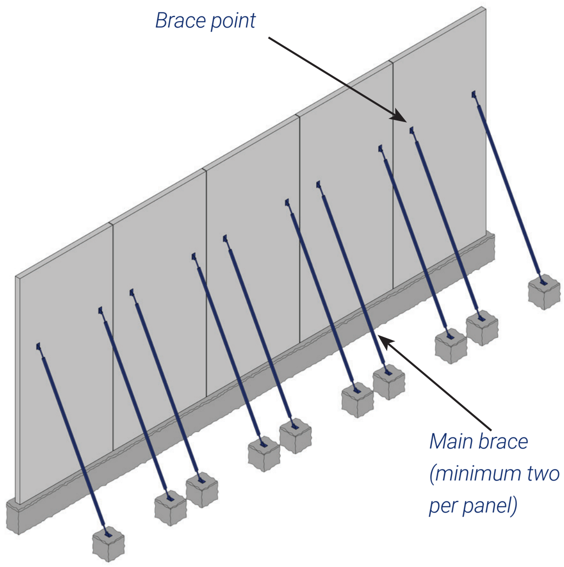

Figure 14 – Typical primary bracing of elements

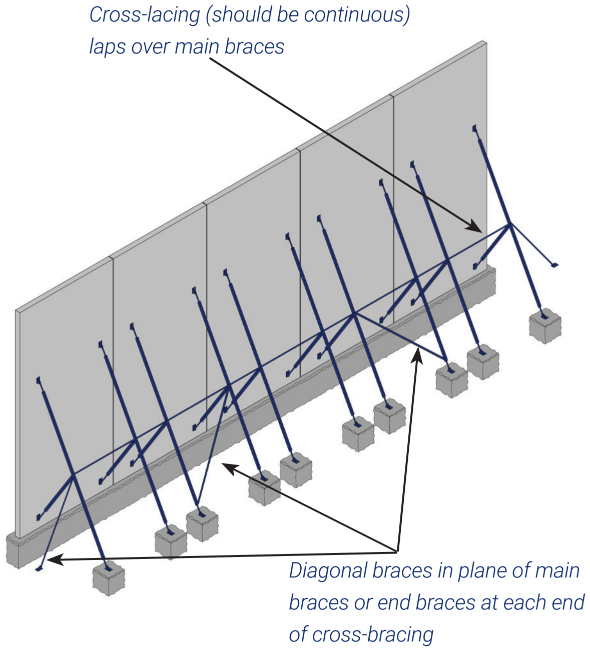

Figure 15 – Primary and secondary bracing of elements

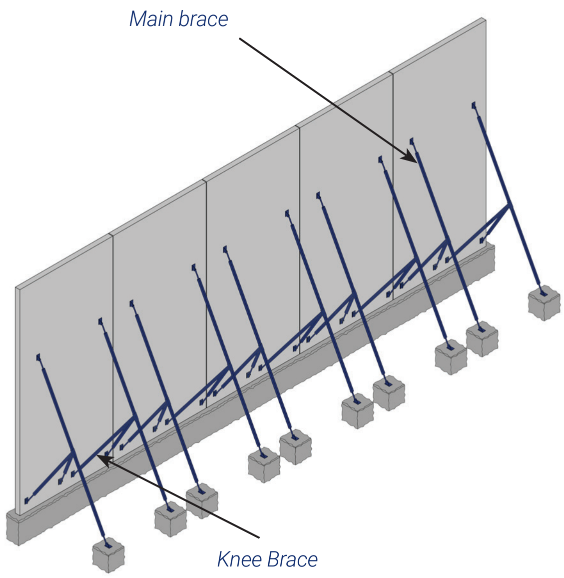

Figure 16 – Primary and secondary bracing of elements

Regardless of where temporary braces are manufactured or sourced, their structural performance data should be provided by the supplier, with independent NATA testing or similar, to show that they comply with the relevant Australian Standards.

This compliance advice applies to all proprietary structural products used in the Australian construction industry.

4.4.3 Temporary brace footings (deadman footings)

Temporary brace footings - or deadman footings - need to be designed to resist all applied loads, including the bracing forces, self-weight of the brace footing and a combination of both, whilst also allowing for the appropriate soil properties. A site-specific geotechnical report (soil investigation report) should be used in this assessment.

Where the temporary support footing is reliant upon the local soil conditions, e.g. screw piles, the Erection Designer must consider possible variations in soil conditions that may occur during the construction period (e.g. high rainfall, a degree of compaction and disturbance during the footing installation, etc).

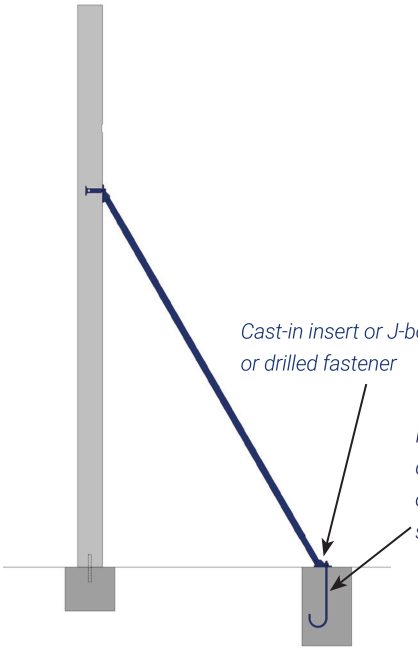

Figure 17 – Cast insitu deadman footing

Details of the temporary footings (including location and size) should be specified as part of the erection documentation, which should also specify the following:

- The characteristic strength of the concrete required to develop the brace insert WLL at the time of bracing ($f_{c.age}$), which is commonly less than the 28-day strength.
- The requirements for in-service loading, durability and any construction requirements such as workability.
- The method of testing to verify the concrete strength, and thus the pull-out capacity of the brace fixing locations, at the time of precast installation. As detailed in AS 3850, in no case should the concrete strength be less than 12 MPa. Where test cylinders are used, they shall be stored and cured in the same environmental conditions (same location) as the brace footing concrete. They must also come from the same concrete pour and be taken at the same time as the pour of the brace footing, and cured and tested in accordance with the appropriate Standards.

4.4.4 Other considerations

In addition to what has been detailed in previous chapters, the Erection Designer also needs to check the shear restraint at the base of the precast concrete element and ensure that the fixings are adequate for the lateral loads.

Dowels may not provide effective lateral restraint until they are grouted and cured. Erection Designers should check that there is sufficient restraint of the dowel and the grout tubes at the base of prefabricated concrete elements to resist the temporary loads during erection, as well as the in-service conditions.

Where dowel bars are used, it is important to ensure that the grout ducts and dowel bars are properly restrained by lateral reinforcement on either side of the grout duct or bar, to resist the horizontal forces at the base of the prefabricated concrete element, as required by AS 3600.

Image 16 – Dowels and starter bars may not provide sufficient lateral restraint until they are grouted and cured

Image 17 – Some elements require both bracing and propping

Importance of grouting

Note: Grouting of prefabricated concrete elements is a critical operation that must be completed correctly and reliably to ensure adequate load transfer between structural elements. In the past, this operation has often not been given the attention that it requires, and failures have occurred. The grouting process should involve specific procedures and quality assurance checks to ensure the completeness of all connections. For further details on grouted connections, refer to National Precast's Understanding Grouted Precast Joints: A guide for engineers and building contractors.

Vertical precast concrete elements (such as walls and columns - refer Image 17) may also require propping in the vertical position where, for instance, there is a large opening at the bottom at one edge. These props need to be designed for the vertical loads that they will take, but they may also be required to be braced, usually with one brace just above the prop and one brace further up the precast elements to avoid twisting.

This information needs to be clearly detailed in the erection documentation, with standard notes and any specific requirements, so that the head contractor and precast erector/installation contractor fully understand all requirements.

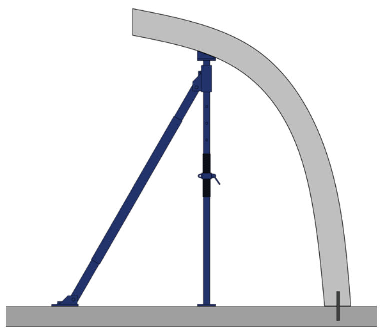

Figure 18 – Designing propping and bracing systems requires careful consideration of the point of bearing by the precast element

4.5 Construction

4.5.1 Installation contractor consideration

Ultimately, the erection or installation of prefabricated concrete elements, including their temporary supports, is the responsibility of the builder or head contractor, who typically appoints the Erection Designer.

The erection/installation contractor has similar responsibilities in relation to bracing and propping of temporary works, as the builder/head contractor does for the construction of the permanent works.

These responsibilities are clearly outlined in the various State and Territory WHS regulators' Codes of Practice and in AS 3850.2 and AS 3850.3.

The main consideration for erection/installation contractors is to execute the specified actions in the precast erection documentation and to do so safely.

If the required information is not provided, installation should not proceed.

Image 18 – Installation of prefabricated concrete panels

It is important to remember that the lifting and erection of a prefabricated element is recognised as a high-risk activity, and as such, should minimise installation time particularly while the load is suspended by the crane.

All preparation works (such as the preparation of braces and fastenings, placement of shims and dowels, protection of assets/overhead wiring and setup of exclusion zones) should be undertaken prior to any lifting and erection.

Image 19 – Placement of shims and other joint preparation works

Although the builder/head-contractor is responsible for the adequacy of the crane set-up area on-site (hardstand), the erection/installation contractor needs to advise and confirm the location of the crane, including outrigger bearing points and precast loaded vehicles, or follow prior advice from the builder/head-contractor.

Once erected or installed (and at regular intervals thereafter), props and braces – together with their fixings and fastenings – must be checked.

The process for inspection should be detailed in the Erection Design documentation. Refer also to State and Territory Codes of Practice where applicable and to AS 3850.2 and AS 3850.3

4.5.2 Brace removal on-site

The Erection Designer must review not only the precast shop drawings and marking plans for the prefabricated concrete elements, but also the architectural and structural drawings to understand how the precast concrete elements form part of the final structure once they are installed and fixed/connected.

For example, are the precast walls loadbearing, non-loadbearing, shear or structural walls, and what role do they play in the final structure?

Answers to these questions will determine the construction procedure and when braces can be removed. This requires inspection and careful consideration by the In-service Designer.

Braces, props and other temporary supports should not be removed until all connections that have been specified by the Erection Designer have been completed, in accordance with the Erection Design Documentation.

These connections may include:

- Grouted dowels/starter bars. Grout must have reached the specified strength (refer to National Precast guide titled Understanding Grouted Precast Joints: A guide for engineers and building contractors).
- Welded connections have been completed and inspected.
- Bolted connections (post-installed and cast-in) are completed.
- In-situ/wet-joints have been cast and have reached the specified concrete strength.
- All other connection details have been completed.

As with the analogy between brace installation and permanent works' construction, the process for brace or prop removal is partly analogous to building demolition works.

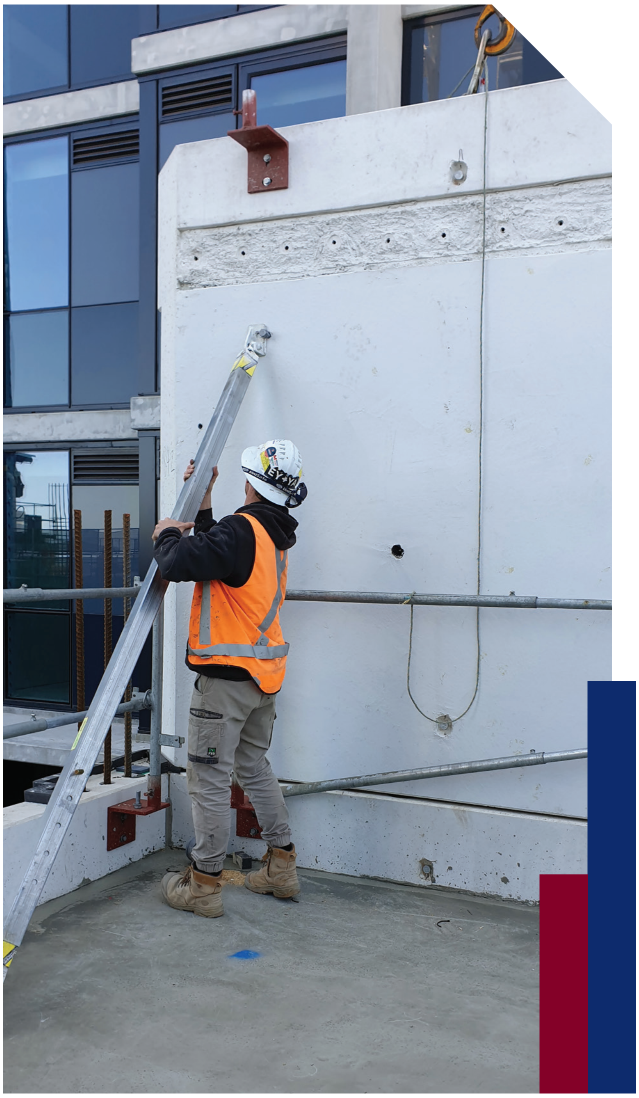

Image 20 – Installation of a brace while the precast element is still supported by the crane

Removal of braces or props is hazardous and requires competent and safe controls.

Precast elements are erected as individual elements, and once they become part of the final structure, only then can the temporary braces be considered for removal.

Written approval from the In-service Designer is required before prop and brace removal, in accordance with Clause 6.3 of AS 3850.2

For more guidance on the removal of temporary supports, refer to AS 3850 Part 2 and Part 3.

5 Structures

The words ‘structure’ and ‘building’ are frequently used interchangeably in lay conversation, but they differ in technical and legal contexts.

In Workplace Health and Safety (WHS) regulations, a structure may be defined as anything that is constructed, whether fixed or moveable, temporary or permanent and **includes** buildings and any component or part of a structure.

Building regulations typically apply to buildings, these being structures with - and whose intended purpose typically involves - a prolonged duration of use by human activity (e.g. for residential, work or leisure purposes).

A completed residential building constructed from precast concrete panels is a structure. Each one of those panels, when erected and temporarily braced during the construction, is a structure but is not a building. And during the construction period, the site is a workplace governed by WHS regulations, whereas the finished residential building is not.

Relating this to the temporary bracing and propping of precast concrete elements, each element is a structure that requires (technically and legally) the same level of engineering competence and construction control as does the finished structure (which may itself be a connected collection of many precast elements).

Image 21 – A multi-level carpark is a regulated and classified building, whereas a bridge is not. Both are structures

The precast elements themselves are required to behave structurally even before they are erected in place, since they must first be lifted from the as-cast position.

Despite their ultimate purpose of being part of the building, they are considered as independent suspended beams or slabs while being lifted.

When temporarily braced, such elements commonly have the structural form of being simply supported propped cantilevers. In the finished building however, they may for example have integral floor slab moment connections, and all stages need to be considered.

Other aspects may add further complexity to the temporary construction phase and the engineering input that is necessary.

For example, a basement wall may be required to retain backfill and withstand water pressures from behind. It will behave differently as a structure in the construction and in-service phases. Similarly, precast floor planks may be pretensioned and consequently may be sensitive to orientation. Or erected wall panels may be supported on post-tensioned floor slabs, which will axially shorten and can displace the wall supports horizontally. Or a precast lift/stair core may be erected early as a freestanding structure, primarily to resist wind loads acting on itself, whereas in the finished building, it may be a strong/stiff core used to resist all lateral forces on the building.

Often the term 'total precast structure' refers to a building that is made up of many structural precast elements being produced as individual elements, e.g. precast walls, columns, beams, floor planks, etc. These elements are then delivered and assembled to create the structure – a kit of parts. In this case, while the previous details of both bracing and propping are very relevant, so is the temporary support of the entire structure while being assembled.

Image 22 – Temporary support of both the individual elements and the total structure must be considered by the Erection Designer for 'total precast structures'.

Image 23 – Precast panels forming lift/stair cores may be self-supporting against wind loads once they are interconnected and no longer require temporary bracing

When considering the bracing of a precast wall panel, this may be fixed at the base to a precast floor plank (acting as the deadman footing). In this case, the ends of the plank may need to be grouted or have locally filled cores to ensure the supporting plank is fixed and unable to slide (note: friction should not be considered) and the load transferred to the foundation.

Where a precast beam is propped to support the temporary load from supported precast planks and an in-situ screed, this propping may also need to consider the lateral restraint of precast columns and panels installed above and the possibility of upper beams, planks and screeds.

In each of these situations, a robust framing system must be considered to ensure the stability of the structure during each stage of construction, along with consideration of alternative load paths, should any part of the temporary works fail, to prevent progressive collapse.

Image 24 – Robust framing to prevent progressive collapse during construction should be considered by the Erection Designer

6 References and Further Guidance

In the past there have been accidents involving the use of prefabricated concrete elements, some of which have resulted in the loss of life. As a result, the erection of prefabricated concrete elements is considered to be a high-risk activity. The introduction of the recent versions of AS 3850 has gone a long way to provide guidance and assistance, however, the role of the Erection Designer and the critical nature of the bracing and propping cannot be over emphasised.

Clients and head contractors have sometimes in the past, ignored the statutory requirement to specify and engage an Erection Designer for the design of temporary works for the erection of prefabricated concrete elements. As previously emphasised, this is now a statutory requirement for buildings via AS 3600, which cannot be ignored.

Below are several relevant documents:

- AS/NZS 1170.0 Structural design actions - General principles
- AS/NZS 1170.1 Structural design actions – Permanent, imposed and other actions
- AS/NZS 1170.2 Structural design actions – Wind actions
- AS/NZS 1576.1 Scaffolding – General requirements
- AS 3600 Concrete structures
- AS 3610.1 Formwork for concrete – Specifications
- AS 3850.1 Prefabricated concrete elements – General requirements
- AS 3850.2 Prefabricated concrete elements – Building requirements
- AS 3850.3 Prefabricated concrete elements – Civil construction
- Victorian Industry Standard, Precast and Tilt-up Concrete for Buildings (Blue Book) for Victoria, Other State and Territory Codes of Practice and the Safe Work Australia guidance material, Guide to managing risks in construction: Prefabricated Concrete
- CIA Recommended Practice Z36 Formwork Handbook 2016

For the last 20 years, National Precast's Precast Concrete Handbook has been a reliable guide on the design and erection of precast. However, it does not cover the design of bracing/propping in detail. CCAA and the CIA also have various guides on precast buildings, but many of these are no longer current.

Issues of poor design and lack of inspections in buildings have been subject to detailed reports and investigations, both in the UK and Australia.

These reports have concluded that there are systemic issues in the construction industry that must be addressed.

For further details of these reports, refer to the following:

- *Building a Safer Future by Dame Judith Hackitt and SCOSS Alert of July 2018 (UK).*
- *SCOSS Alert https://www.structural-safety.org/media/502426/scoss-alert-effects-ofscale.pdf (UK).*
- *The Shergold & Weir Building Confidence Report February 2018 (AUS).*

7. Appendix

7.1 Inspection for torque-controlled expansion anchors

While installation instruction material should be sourced from the anchor manufacturer and followed, some generic guidance material on the inspection of torque-controlled expansion anchors can be found below:

Post-installation inspection must be conducted weekly and after major weather events to ensure brace inserts are secure, in accordance with AS 3850.

An appropriate method of inspection for torque-controlled expansion anchors may include the following steps (subject to the endorsement or approval by the proprietary supplier and Erection Designer):

- Draw aligned reference marks on the bolt head and the surrounding fixture surface to enable inspection of any bolt rotation;
- Using a calibrated torque wrench, apply approximately two-thirds of the rated installation torque in a clockwise direction (or in accordance with the manufacturer's instruction);
- Inspect and record any turning of the bolt head. If any anchor turns more than a one-quarter turn (90°), **report this immediately to the responsible authority on-site**; and

It is recommended that this post-installation inspection process is repeated at regular **weekly intervals** and as soon as practicable after any **significant weather events** or any **prefabricated concrete element impacts** on-site. If the total accumulated rotation of any bolt head exceeds onehalf- turn (180°) after repeated inspections, report this immediately to the responsible authority on-site.

Any decision to tighten the reported fastener because of a post-installation inspection shall be made by the qualified person on-site, in consultation with the Erection Designer.

Note: Fastener (anchor) installation post-installation inspection is a requirement of AS 3850.

7.2 Other information (further general guidance)

Below are some helpful hints that should be considered when undertaking a bracing design for a prefabricated concrete element:

1) It should be noted that specific guidance for bracing is given in AS 3850 - Design of temporary bracing for vertical elements. In addition to the wind, it may include other superimposed loads, such as loads incurred from concrete elements being poured against the prefabricated concrete element, or the vertical deflections of cranked beams between walls pushing the walls out. The temporary bracing design should be explicit about what loading sources are included and excluded from the design.

Note: the risks of allowing soil loads, and the like, to be imposed on temporary bracing or propping should be avoided.

2) Although erected elements typically sit on a flat base and their dead weight may provide a restoring moment to overturning, this should be ignored as usually, elements initially bear onto packing shims whose dimensions, orientation and placement are often not carefully controlled. Therefore, this base connection should be considered to be pinned.

3) Bracing design documentation should provide sufficient information to enable checking by an independent engineer.

4) Where braces are to be anchored into early-age concrete, particular care is required to verify and manage the actual in-situ concrete strength (in comparison to what is assumed in the bracing specification). Refer to AS 3850 and additional guidance published by WorkSafe Victoria.

5) Bracing design documentation should state all critical information necessary for the safe use and operation of bracing components, in addition to that required from any product suppliers.

6) Proprietary structural components (e.g. mechanical expansion anchors, bolts, braces, props, etc.) must be specified, installed and maintained in accordance with the information published by their supplier.

Note: suppliers of mechanical expansion anchors have specific installation and residual torque requirements. Refer AS 3850 for further information.

7) Where additional footings are required to support temporary braces, they must be designed and detailed by the Erection Designer. In many situations, the concrete slab is often used for brace fixing. However, for thin slabs, the slab may also need to be checked for pull-out capacity by the Erection Designer.

8) Commonly used braces behave as pin-ended columns and buckling capacity may be increased by the addition of other appropriate members (such as knee bracing) which restrain buckling deflection of the main brace. Refer to AS 3850 and Section 4.3 Design of bracing and propping. For shorter braces, this may not be beneficial since the overall capacity is typically limited by the brace-end anchoring. For the design of bracing to resist the overturning of precast elements, a static analysis is especially important. It is essential to ensure that the free-body diagram of the precast concrete element being analysed accurately represents what will occur on-site. This analysis usually involves simple statics, and it does not, in most cases, require sophisticated modelling.

9) Wherever possible, more than 2 braces on any face of a prefabricated concrete element should be avoided as it is difficult to control the distribution of the loads between more than 2 braces. In some cases, for example, for narrow wall panels or columns, it may be necessary to brace in 2 orthogonal directions.

10) The builder or head contractor needs to account for potential exclusion zones and drop zones of erected precast elements in the site risk analysis. An exclusion zone is a designated restricted area in and around the flight path of the precast element during the lifting handling and placing on site. A drop zone is a designated restricted area in and around a building construction site through, or onto which, items may potentially fall. In the event of failure, such items could include a falling precast element.

For specific guidance for propping design, refer to Section 4.2 of this Guide. Additional relevant information may also be found in AS 3610.

Note: The drop zone and exclusion zone of each building element should be detailed in the Contractor's Safe Work Method Statement.

Below is further technical guidance that may assist Erection Designers.

1) From AS 3850.2, the bracing documentation should state the assessed 'Terrain Category', 'Wind Region' and 'Design Wind Speed' adopted for the bracing and propping design.

2) Bracing design documentation should state the resultant induced wind pressure and any other loads that have been considered. This documentation should also specify the induced bracing and propping reactions so that the In-service and Erection Designers can make provisions for their support.

3) Note 4 of Table F2 in AS 1170.0, refers to structures in wind Regions C and D (i.e., cyclonic regions, as defined in AS/NZS 1170.2) that are erected and remain erected only from May to October. These may be designed for regional wind speeds given in AS/NZS 1170.2, for Region A, or alternatively from a specific analysis of non-cyclonic wind events for the site. A structure not designed for cyclonic wind speeds shall not remain erected during the months of November to April inclusive. Note the apparent anomaly wherein Region B is excluded from this concession. Given the practical difficulty of controlling this construction timing risk, it is prudent to ignore this concession and design for the higher wind forces.

4) The worst case for the various 'Multipliers' via AS/NZS 1170.2 is a value of 1.0 (recommended) but note that 'Wind Direction Multiplier' M_d via Cl 3.3, has a worst-case of 0.95 for Regions B, C, and D (considering resultants and overturning effects).

5) For assessing C_{shp} for precast elements, they should be considered as freestanding walls in accordance with Appendix B of AS/NZS 1170.2. Typical max $C_{p,n}$ of 1.3 is usually appropriate, and K_a, K_l, K_p are all 1.0.

6) The calculated wind force resultant should be applied at the centroid of the elevation area it acts upon. Note that this does not always coincide with the element's centre of gravity (CoG).

7.3 Typical notes for structural drawing

The following are some standard notes that could be used in the erection documentation and/or structural drawings as required. Notes should be amended to suit specific project conditions and requirements.

These notes assume that a Safe Work Method Statement (SWMS) for the erection has been prepared to show the method of lifting and placing precast concrete elements.

The following notes do not include rigging or lifting and rotation information, which are all the responsibility of the builder/head contractor.

1) Note: The word fastener is used and replaces the words anchor, expansion anchor, fixing and similar.

2) It is the responsibility of the precast concrete manufacturer to ensure that the specified cast-in inserts and lifters are positioned correctly and in accordance with the approved shop drawings, and that the appropriate component reinforcement (tension and shear bars) is provided in accordance with the component manufacturer's technical information.

3) The minimum concrete strength of the prefabricated concrete element for lifting and bracing **on-site** is 25MPa (required concrete strengths to be specified by the Erection Designer).

Note: The minimum concrete strength for de-moulding in the factory is commonly 15MPa, while the minimum concrete strength for lifting and bracing on-site is commonly 25MPa and a minimum 28-day strength of 40MPa.

4) The design of the bracing has assumed that only wind loads are applied to the prefabricated concrete elements during construction. DO NOT allow other lateral or vertical loads to be applied to the prefabricated concrete elements.

5) Only braces as shown on the erection documentation, should be used. These should be fixed to the prefabricated concrete elements and to the supporting structure (typically slab or footing). All braces must be positioned at the nominated locations and dimensions shown in the erection documentation. After braces are no longer required and their removal has been approved by the Erection Designer, remove any fastener spacers and the shank before repairing the hole required for the post-installed brace fastener (if required).

6) Use only the specified types of braces and brace anchors. Substitution of braces, props or fasteners shall only be used with the written approval of the Erection Designer.

7) All braces are to be nominally perpendicular to the face of the prefabricated walls in plan,unless otherwise shown on the erection documentation. Braces may be splayed in plan by no more than 5° from perpendicular to the face of the wall. Where braces must be splayed beyond 5° (to avoid other structures, braces, construction joints etc.), refer to the Erection Designer for specific information.

8) Cast-in bracing ferrules (cast-in bracing inserts) that have been cast into the prefabricated concrete elements are recommended to be hot-dip galvanised M20 cast-in foot inserts as a minimum (as shown on the shop drawings) or be another approved insert (the In-service Designer must specify the durability requirements).

9) Fix the top of the braces to the prefabricated concrete element with 1 x M20 Class 4.6/S bolt (to AS/NZS 1252) to the brace fixing as detailed. Do not use Class 8.8 bolts into cast-in inserts for bracing.

10) A minimum distance should be specified - typically 300mm to any free edge of concrete slabs - in the Erection Design Documentation, including construction joints (CJ) and saw cut joints (SCJ) for any bracing insert (nominal).

11) If a cast-in insert has been missed, contact the Erection Designer for an alternative fixing method.

12) Where a specified cast-in insert has not been cast in place, a typical rectification may be to fix an appropriate proprietary post-installed bracing fastener per brace - as the bracing insert - where they are not exposed to view. After they are no longer required, remove the spacer and the shank before repairing the hole required for the temporary fastener. Where exposed to view or externally used, a specific (insert supplier and type of fastener) stainless or galvanised steel fastener should be specified.

13) The following wording should be used on the erection documentation: ‘The brace fasteners are to be (*insert specified fastener*) supplied by (*insert supplier*)’. These are to be heavy duty, load-controlled torque setting expansion fasteners (tested in accordance with AS 3850.1 and typically 14mm). Other fasteners are only acceptable when approved in writing by the Erection Designer.

14) Requirements for brace fastener (anchor) installation and bracing of prefabricated concrete requirements are as follows:

- Actual concrete compressive strength (f_{cm}) of the concrete into which the brace fastener is to be used for bracing all prefabricated elements, should be a minimum of 20 MPa (according to the manufacturer’s documentation);

- The minimum concrete edge distance from a post-installed fastener (including holes and voids) is 300 mm;

- The minimum fastener spacing should be such that one fastener is applied per brace to connect the bottom of the brace to the base concrete unless otherwise shown. Where double foot anchors are shown, provide two brace fasteners, nominally 170 mm apart;

- Thoroughly blow or vacuum the dust from the hole (in accordance with the manufacturer’s technical data prior to installing);

- Place the foot of the brace over the drilled hole, flush with the concrete and drive the brace anchor through the hole in the foot of the brace into the drilled hole with two to five blows of a hammer or until the washer of the brace anchor is flush with the top of the foot of the brace;

- Tighten the bolt in the brace anchor (bracing insert) using a calibrated torque wrench (do not use an impact drill) until the minimum torque specified by the brace anchor supplier has been correctly applied; and

- Check torque after initial erection and in accordance with the Erection Documentation.

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