Capacity of Bracing Inserts

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OUTLINE
- Australian Engineered Fasteners and Anchors Council
- Design of anchors for use in concrete
- AS3850-2003
- AS3850.1
- AEFAC resources
- Summary

AEFAC FOUNDING BOARD MEMBERS

AEFAC SUPPORTING MEMBERS

Guidelines for the specification of anchors
For Designers

Training & certification for installers of anchors
For Contractors

Minimum performance & standard specification
For Manufacturers

Guideline for field testing & certification of anchors
For Field Engineers

Research & Development
For anchor industry
Overview

- Based on European guidelines
- Prequalification based on ETAG
- Referencing Australian standards for steel and concrete

Scope – safety-critical applications

- **Post-installed**
  - Mechanical anchors
  - Chemical anchors
- **Cast-in**
  - Anchor channel

Exclusions

- Design of fasteners for lifting, transport and erection (brace inserts, lifting inserts, etc.) – refer to AS 3850
- Seismic, fatigue, durability, fire
- Post installed rebar – refer AEFAC Technical Note

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The critical tensile capacity is the lesser of—

(a) the pullout load, usually concrete cone failure; or
(b) the ‘first slip load’ due to cyclic loads.

The critical shear capacity is the lesser of—

(i) the failure load of the steel bolt (or bolt and sleeve where applicable); or
(ii) the failure load due to edge breakout of the concrete where the anchor is close to an edge.

2.2 WORKING LOAD LIMIT (WLL)

The WLL shall be derived from one of the following, as appropriate:

By dividing the multiple of the mean value of the test results ($x$) (see Appendix A) and the capacity reduction factor ($\phi$), by the limit state factor (LSF) and the sampling factor, $k$, i.e.

$$ WLL = \frac{\phi x}{k \cdot (LSF)}; \text{ or} $$

the value of $\phi$ shall be chosen from the appropriate Australian Standard.

For the pull-out of a lifting insert, or cast-in ferrule, from concrete, the value of $\phi$ shall not be greater than 0.6.

$$ WLL = \frac{x}{2.5} $$
Expansion anchors: Expansion anchors for brace fixing inserts shall be of the load-controlled type. Where these anchors are used, the WLL shall be limited to 0.65 of the ‘first slip load’, established in accordance with Appendix A.

Load at approximately 0.1mm ranges between 12 – 29 kN.
Significant scatter of load observed within a given product.

For the same anchor, check its ultimate capacity for cone failure using Limit State Design

Characteristic strength = $11.0 \sqrt{f_c h_{ef}^{1.5}}$

Characteristic strength = $11.0 \sqrt{20(80)^{1.5}} = 35,200 N = 35.2 kN$

Design Strength = $\phi \times 35.2 = 0.67 \times 35.2 = 23.6 kN$

If WLL is based on characteristic strength rather than average strength
WLL = 35.2/2.5 = 14.1 kN (1.4T)
Integrity tests:
Insert shall not fail by breakage or cause failure of the concrete when the application of twice the specified installation torque is applied.

Basic tension tests:
Apply tension load up to failure. Determine characterise strength (Ru) based on CoV and no of samples.

Cyclic tension tests:
Apply 1000 load cycles (up to 0.6 Ru). Residual displacement to be \( \leq 0.25\text{mm} \). Then apply tension to failure.

In determining the ultimate capacity of anchor in tension we now consider:
- Cone failure
- Steel failure
- Pull out failure
- Uncontrolled slip
- Residual displacement due to cyclic loading

WLL = Characteristic strength/2.25
FAQ

- Refer to AEFAC’s website [www.aefac.org.au](http://www.aefac.org.au) for FREQUENTLY ASKED QUESTIONS on SA TS 101

Design for post-installed rebar for development length

Design as per AS 3600

\[ L_{ovt} = \frac{(0.5k_1 \cdot k_2 \cdot f_{cy} \cdot d_b)}{k_2 \cdot \sqrt{f'_c}} \geq 29k_1 \cdot d_b \]

This formula is for cast-in rebar

For post-installed rebar to act as cast-in rebar, system need to be be qualified to **EOTA TR 023**

Installation is **critical**:
- Tools required
- Deep cleaning
- Installer must be **competent** and trained for specific application

AEFAC TECHNICAL NOTE – ENGINEERING GENERAL NOTES

**SUMMARY**

- Bracing inserts testing and evaluation methods in AS3850 – 2003 lacked consistency and rigour

- The modified testing and evaluation methods in AS3850.1-2015 follow best practice and established design processes.

- There is a reduction in rated WLL for inserts due to the new testing and evaluation methods by about 30%.
Lifting Anchor Design in Accordance with AS 3850

Andreas Boomkamp
Ancon Building Products

November 8, 2018
Swinburne University of Technology

Content
- Concrete Precast is all around us
- Lifting Systems
- Codes and standards
- Lifting design according to AS 3850:2015

Precast Concrete is all around us …

Perth Stadium, Perth, WA
Mill Road Skyhouse Liverpool, NSW
Ravenhill Prison, Ravenhill, VIC
Wheatstone LNG Project, Wheatstone, WA
Swinburne University, VIC

Retaining Wall
Advantages of Precast Concrete

- Higher quality as produced in controlled environment
- Lower cost due to optimisation of work flow
- Reduction of weather influence on speed and quality
- Speeds up the construction process on site
- Cost reduction through re-use of formwork
- Accelerated curing through heating the precast parts
- With the ability to tightly control the process more durable concrete can be achieved

Content

- Concrete Precast is all around us
- Lifting Systems
- Codes and standards
- Lifting design according to AS 3850:2015
Unique Challenges of Precast Concrete

Connections in precast

- For transportation bulky concrete members to be divided in multiple items
- Load bearing permanent connections are required on site
- Temporary connections are needed to resist wind loads.

Special connections (permanent and temporary) required!

Lifting Connections

- For transportation bulky concrete members to be divided in multiple items
- Load bearing permanent connections are required on site
- Temporary connections are needed to resist wind loads.

Special connections (permanent and temporary) required!

Lifting of Precast Concrete

- Concrete parts produced away from the building site
- Orientation of the item often different for production, transportation, placement

Special items for lifting required!

Lifting of Precast Concrete

“Handmade” solutions to lift precast

“Handmade Lifting Systems” can cause catastrophic failures!
Lifting Systems

Cone Anchor System
- Based on a system developed by Dr. Häussler in Germany
- Quick, safe connection
- Cannot disconnect under load
- Recessed below the surface, no damage
- No obstruction, Visual connection confirmation
- Engineered design

Edge Lifting Systems
- Systems to allow handling wall elements that are casted flat
- Proprietary lifting anchors
- Capacities based on testing

Lifting Loops
- Steel cable loops
- Proprietary lifting anchors
- Used for heavy precast items like bridge beams

Content
- Concrete Precast is all around us
- Lifting Systems
- Codes and standards
- Lifting design according to AS 3850:2015

When precast became more popular…

… more accidents happened!
Design of Prefabricated Concrete Elements

In-service Design:
- Design for the service life of the structure
- According to AS 3600
- Loading according to AS 1170
- Using characteristic capacity and reduction factors
- Performed by design engineer (in-service designer)

Erection Design:
- Design of the erection an temporary support until completion
- Includes all de-moulding, storage, transport, lifting, bracing, propping
- According to AS 3850 and National Code of practice
- Loading according to AS 1170
- Using Working Load Limit approach
- Performed by erection design engineer

Implementation:
- First released in 1990
- Multiple revisions in 1992, 2003 and 2009
- Current revision released in 2015
- Amendments for Part 1 and 2 to be released later in 2018

Scope:
- Part 1: General – Amendment towards end of 2018
  - Materials, components and equipment
- Part 2: Building Construction – Amendment within the next weeks
  - Planning, construction, design, casing, transportation, erection and incorporation into the final structure
  - wall, floor & façade elements, columns, beams, stairs, planters, ...
- Part 3: Civil Construction (Currently under development – to be released 2020)
  - Civil construction (box culverts, bridge beams, pipes, ...)

National Code of Practice

Currently being revised for consistence with AS3850:2015

Road Authority Requirements

Technical Specifications available by road authorities like TMR (QLD)
Lifting Design – Step-by-Step Guide

Step 1: Determine the number of lifting points required for stability

The number of lifting points depends on the type of the precast element:

- Beam
- Plate-like
- Column

<table>
<thead>
<tr>
<th>Type</th>
<th>Min. lifting points for stability</th>
<th>Rigging sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Plate-like</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Column</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>
Lifting Design – Step-by-Step Guide

Step 1: Determine the number of lifting points required for stability

<table>
<thead>
<tr>
<th>Type</th>
<th>Min. lifting points for stability</th>
<th>Rigging sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plate-Like</td>
<td>3*</td>
<td><img src="Plate-Like" alt="Diagram" /></td>
</tr>
<tr>
<td></td>
<td><strong>4</strong></td>
<td></td>
</tr>
</tbody>
</table>

* Not recommended

Step 2: Calculation of the concrete element weight

\[
\text{Volume} \times \text{Density} = \text{Weight}
\]

Density of normal reinforced concrete: 2,500 kg/m³

Step 3: Define the optimum rigging system

Main functions of the correct rigging system:

- Ensure equalised loading between the Lifting points
- Provide Stability

→ The centre of lift of the lifting points should be as close as possible to the centre of gravity of the object
Lifting Design – Step-by-Step Guide

Step 3: Define the optimum rigging system

Systems that provide stability while distributing the loads equally to the lifting points:

**Image of rigging system with balanced loads**

Systems that do **not** equally distribute the loads:

**Image of rigging system with unbalanced loads**

The red chains will **not** take over loads.

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Lifting Design – Step-by-Step Guide

Step 3: Define the optimum rigging system

**Table: Possible Rigging Mistakes**

| Incorrect rigging can lead to failures of lifting inserts, rigging components and the precast concrete element! |

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Lifting Design – Step-by-Step Guide

Step 4: Determine the static load at each lifting point

The static load $N_s$ is calculated as follows:

$$N_s = Z \cdot \frac{P}{n}$$

With:

- $N_s$: Static Load on the lifting insert
- $Z$: Sling angle factor
- $P$: Weight of the precast concrete element
- $n$: Number of equally loaded lifting inserts
Step 4: Determine the static load at each lifting point

<table>
<thead>
<tr>
<th>Sling angle $\alpha$</th>
<th>Angle at anchor $\beta = \alpha/2$</th>
<th>Sling angle factor &quot;Z&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°</td>
<td>-</td>
<td>1.00</td>
</tr>
<tr>
<td>15°</td>
<td>7.5°</td>
<td>1.01</td>
</tr>
<tr>
<td>30°</td>
<td>15°</td>
<td>1.04</td>
</tr>
<tr>
<td>45°</td>
<td>22.5°</td>
<td>1.08</td>
</tr>
<tr>
<td>60°</td>
<td>30°</td>
<td>1.16</td>
</tr>
<tr>
<td>90°</td>
<td>45°</td>
<td>1.42</td>
</tr>
<tr>
<td>120°</td>
<td>60°</td>
<td>2.00</td>
</tr>
</tbody>
</table>

Sling angles greater than 120° are not permitted! (AS 3850.2:2015 – 2.5.2)

Changes to the sling angle have a big influence on the sling forces!

Step 5: Calculation of the design tension load $N^*$

The load $N^*$ includes the multiplying factors for suction $\xi$ for the load case de-moulding and the dynamic effects $\Psi_{dyne}$ and service life $\Psi_{sl}$ for the transportation / installation:

**Load Case de-moulding:**

$$N^* = \xi \cdot N_s$$

**Load Case Transport / Installation:**

$$N^* = \Psi_{dyne} \cdot \Psi_{sl} \cdot N_s$$

AS 3850.2:2015 – Chapter 2.5.1

**Suction Factor $\xi$:**
- Consideration of suction and friction between precast element and formwork
- Depending on formwork surface and preparation
- Only for first lift of the casting bed
- Specified in AS 3850.2 – Table 2.2

**TABLE 2.2**

<table>
<thead>
<tr>
<th>Suction condition</th>
<th>Suction factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>When calculating inert loads and bending moments at the point of element lift-off from a concrete casting bed</td>
<td>20.2</td>
</tr>
<tr>
<td>When calculating inert loads and bending moments at the point of element lift-off from a concrete casting bed</td>
<td>30.2</td>
</tr>
<tr>
<td>Other casting surfaces to account for the effects of suction and adhesion (as per standard)</td>
<td>As appropriate</td>
</tr>
</tbody>
</table>
Lifting Design – Step-by-Step Guide

Step 5: Calculation of the design tension load N*

Dynamic Factor $\Psi_{\text{dyn}}$:

- Consideration of dynamic effects like "bouncing" of suspended loads
- Significant impact when travelling over ground
- Different dynamic factors can apply for different lifting procedures of the same item
- Specified in AS 3850.2 – Table 2.3

<table>
<thead>
<tr>
<th>Mean of transportation</th>
<th>Dynamic Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>A stationary crane (including an overload ready crane or a crane standing on an uneven surface)</td>
<td>1.2</td>
</tr>
<tr>
<td>A mobile crane (including a crane ready to lift a mobile crane or a mobile crane ready to travel)</td>
<td>1.0</td>
</tr>
<tr>
<td>Tracked mobile lifting equipment (including rubber tyred travelling with the suspended load on a prepared even surface)</td>
<td>1.7</td>
</tr>
<tr>
<td>Non-tracked mobile lifting equipment (including rubber tyred travelling with the suspended load on an unprepared even surface)</td>
<td>2.0</td>
</tr>
<tr>
<td>All mobile equipment travelling with the load suspended on an unprepared even surface (including lifting)</td>
<td>2.9</td>
</tr>
</tbody>
</table>

Service Life Factor $\Psi_{\text{sif}}$:

- Consideration of reoccurring lifts other than what is needed for manufacture, delivery and installation

<table>
<thead>
<tr>
<th>Design Lifting condition</th>
<th>Load factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lifting and handling during all stages of manufacture, delivery and installation</td>
<td>$\Psi_{\text{sif}} \geq 1.0$</td>
</tr>
<tr>
<td>Applications requiring repetitive re-lifting of a concrete element during its service life (e.g. concrete road barriers) – AS 3850.2:2015 Table 2.4</td>
<td>$\Psi_{\text{sif}} \geq 1.6$</td>
</tr>
</tbody>
</table>

AS 3850.1:2015 – Chapter 2.5.3.2

Step 6: Select the required Lifting Insert

Selection of the required Lifting Insert based on:

- Working Load Limit (WLL) for the steel of the insert itself
- Working Load Limit (WLL) for the concrete the insert is installed in
- Factor of Safety (FoS) for both capacities is 2.25 in accordance with AS 3850
- Concrete capacity based on CCD method (unreinforced concrete) or supplier testing (reinforced concrete)

Lifting Design – Step-by-Step Guide

Step 6: Design of precast element for all actions imposed during lifting, transportation and installation

Design considerations:

- Erection design engineer must ensure that element strength is sufficient to withstand all imposed loads during all lifting procedures
- Design for unreinforced concrete limiting the tension to $0.41 \cdot \sqrt{f_{\text{age}}}$
- To limit tension loads refer to reinforced concrete design (according to AS 3600) or add strongbacks
Thank you!
Preamble

- AS3850.1 – 2015 introduced a number of changes to capacity derivation methods previously utilised in AS3850 – 2003
- These changes have resulted in reductions to published capacities for post installed brace inserts
- These reductions constitute decreases of up to 30%
- How does this impact Precast Panel construction?

Agenda

- Review the 2003 approach to post installed brace insert capacity derivation techniques.
- Review and contrast the 2015 approach.
- Explore a dataset of 100 Precast Panel projects to understand impacts of the changes on the # braces required.

Post installed brace anchors

- 20mm diameter drilled hole
- Slot spanning washer
- Large 30mm AF hex head
- Large shear diameter
- M14 bolt
- Friction modifiers to improve torque / preload efficiency
Post installed brace anchors – why call them out?

- Precast panel bracing is a unique application
- Inserts used in pairs - no redundancy in use
- Load case is wind loads
- Temporary / short term use

AS3850 – 2003: Capacity derivation

2.2 WORKING LOAD LIMIT (WLL)
The WLL shall be derived from one of the following, as appropriate:
(a) The relevant Australian Standard.
(b) By dividing \( \psi R_u \), obtained from the relevant Australian Standard, by the limit state factor (LSF).
(c) By dividing the multiple of the mean value of the test results (\( \bar{x} \)) (see Appendix A) and the capacity reduction factor (\( \psi \)), by the limit state factor (LSF) and the sampling factor, \( k_s \), i.e.

\[
WLL = \frac{\psi \bar{x}}{k_s \text{ (LSF)}} \; \text{or}
\]

the value of \( \psi \) shall be chosen from the appropriate Australian Standard.

For the pull-out of a lifting insert, or cast-in ferrule, from concrete, the value of \( \psi \) shall not be greater than 0.6.

AS3850 – 2003: Capacity derivation

- What is this Limit State Factor (LSF)?

1.3.13 LSF (limit state factor)
The sum of each of the appropriate load components multiplied by the appropriate load factors, divided by the sum of the unfactored load components.

- Interesting use of a design action effect measure in a capacity derivation model...
AS3850 – 2003: Capacity derivation

A8.2 Testing parameters for expansion anchors to be used as brace inserts

A8.2.1 General

The WLL of panel brace fixings shall be determined by measuring the residual preload in tension 14 days after setting into 20±2 MPa concrete. The anchors are then loaded in tension until failure, and the characteristic ultimate tensile capacity calculated from the results.

- The concrete reference is ambiguous and is susceptible to interpretation...

- Infers published capacity applicable at 20MPa concrete strength

A8.2.5 Test method

Anchors shall be loaded after 14 days to remove the residual preload. Preload is equalized when the fixture plate can be rotated by application of a load of 1 kg to the end of the handle. The load required to equalize the clamping force shall be recorded as the 'residual clamping load'. The anchors shall then be tested to failure.

- Premise of this method is that preload is a direct measure of resistance to applied load, the 14 days period allowing for concrete creep effects over the typical duration of a panel braced on a site

A8.2.3 Setting

Hole diameter shall be the nominal drill bit diameter +0.3 mm to +0.4 mm. The anchor shall be inserted into the hole in the concrete through a fixture. The fixture shall be a 20 mm thick × 100 mm diameter steel cylinder with a hole in the centre with a diameter equal to the nominal outer diameter of the anchor +2 mm to +4 mm. The fixture shall be fitted with a 16 mm diameter × 100 mm long handle extending radially from its upper surface. A steel sheet with minimum thickness 0.5 mm, hot-dip zinc coated to AS 1397, with the same dimensions as the fixture, shall be inserted between the steel fixture and the concrete. Ensure that the fixture does not rotate while the anchor is being tightened.

The anchor shall remain undisturbed for a period not less than 14 days from the date of installation.

A8.2.4 Sample size

A minimum of 10 anchors shall be tested.

A8.2.6 Load application

Load is applied carefully while a spotter looks for movement of the 'saucepan' handle.

- Many variables influence the outcome:
  - Concrete surface roughness
  - Co-ordination of spotting and recording
  - Galv. Plate
    - Thickness
    - Finish
    - Cleanliness
- Highly 'susceptible' test setup
AS3850 – 2003: Capacity derivation

- Unfortunately an older reference to ‘first slip load’ remains – allowing another means of calculating capacity

A8.2.6 Expansion anchors

Expansion anchors shall be tested to determine the first slip load. The procedure shall be as follows:

(a) Install the anchor in accordance with the manufacturer’s recommendations, paying particular attention to the correct drilling of holes and the correct installation torque.

(b) Progressively apply the load until the fixing has moved 0.1 mm.

(c) Record this load as the first slip load.

(iii) Expansion anchors: Expansion anchors for brace fixing inserts shall be of the load-controlled type. Where these anchors are used, the WLL shall be limited to 0.65 of the “first slip load”, established in accordance with Appendix A.

AS3850 – 2003: Summary

- Agricultural test methodology
  - Uses indirect measures
  - Susceptible to interpretation

- Conflicting capacity derivation methods
  - First slip vs retained preload methods

- Incorporation of LSF in capacity equation
**AS3850.1 – 2015: Capacity derivation**

**TABLE A5**

<table>
<thead>
<tr>
<th>Test</th>
<th>Series</th>
<th>Age at installation, days</th>
<th>Age at test, days</th>
<th>Mean concrete strength, MPa</th>
<th>Drift limit diameter, mm</th>
<th>No. of tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>Torque</td>
<td>2</td>
<td>28</td>
<td>28</td>
<td>32–40</td>
<td>0.025</td>
<td>5</td>
</tr>
<tr>
<td>Tension</td>
<td>1</td>
<td>7</td>
<td>7</td>
<td>20–36</td>
<td>0.025</td>
<td>5</td>
</tr>
<tr>
<td>Cyclic</td>
<td>1</td>
<td>7</td>
<td>5–9</td>
<td>20–36 at 7 days*</td>
<td>0.025</td>
<td>5</td>
</tr>
<tr>
<td>Shear</td>
<td>1</td>
<td>7</td>
<td>7</td>
<td>20–36</td>
<td>0.025</td>
<td>5</td>
</tr>
</tbody>
</table>

* Adjustment for higher concrete strength shall be made based on square-root of strength.

**Basic tension test**

- Additional acceptance criteria
  - \( N_1 = \text{lesser of } 0.8 \, \text{Nu, } A_s \, f_{sy} \)
- Uncontrolled displacement not permitted below \( N_1 \)
- Results normalised for 20MPa concrete compressive strength

**Cyclic tension test**

- 1,000 cycles
  - Load cycled from \( 0.02 R_u, N \) to \( 0.6 R_u, N \) – \( R_u, N \) from basic tensile tests
  - Cycling rate = 1 to 2 Hz
  - Residual displacement post test < 0.25mm
- This approach relates to the ultimate one hour wind loading condition for a 100 YRP event.
- Results normalised for 20MPa concrete compressive strength
AS3850.1 – 2015: Capacity derivation

Cyclic Testing Methodology for Temporary Propping of Tilt-up Panels for Wind Loading Effects

Nicholas Haritos¹, David Heath², Emad F Gad³ and John I. Wilson⁴

A much simplified method, labelled here as the dynamic Simplified Testing Procedure, or STP, uses 1000 cycles at 1-2 Hz ranging from 0 to 60% of ultimate prop force on the prop-fixture test assembly as the prequalification test of anchor systems in panel propping applications. This procedure can be related to the ultimate one-hour wind loading condition following cycle counting via a rainfall investigation of this simulated ultimate wind loading condition. It is found from the sample panel investigation performed in this paper that 1 in 7 cycle counts at ultimate exceed the peak load associated with the STP, which infers that 6 out of 7 cycles are below this peak.

AS3850.1 – 2015: Summary

• Simplified, more direct testing program
• Unambiguous calculation of capacity
• Probabilistic approach to cyclic test method
• Normalised to 20MPa concrete strength

AS3850.1 – 2015: Capacity derivation

• Torque test
  • Evaluates insert ability to resist over torque during install
  • Criteria
    • Torque = 1.3 x Install torque applied
    • Induced tensile load recorded
      • 95% fractile of tensile load < Bolt yield (A_fs)
    • Insert shall be removable from drilled hole
  • If criteria not met, reset test (lowering torque)
    • All series 1 tests are then repeated using reduced torque value

100 Projects – impact on # of braces required

• If brace insert capacity has been reduced by up to 30%, how does this impact the # of braces required?
• To help answer this question, a sample set of 100 randomly selected Precast Panel projects was investigated.
• Impact assessment based on change to # braces only, no re-design of panel configuration (optimisation) is considered
100 Projects – impact on # of braces required

<table>
<thead>
<tr>
<th>State</th>
<th># Projects</th>
<th># Panels</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACT</td>
<td>1</td>
<td>19</td>
</tr>
<tr>
<td>NSW</td>
<td>10</td>
<td>333</td>
</tr>
<tr>
<td>NT</td>
<td>3</td>
<td>45</td>
</tr>
<tr>
<td>QLD</td>
<td>12</td>
<td>253</td>
</tr>
<tr>
<td>VIC</td>
<td>40</td>
<td>1110</td>
</tr>
<tr>
<td>WA</td>
<td>34</td>
<td>788</td>
</tr>
<tr>
<td><strong>Grand Total</strong></td>
<td><strong>100</strong></td>
<td><strong>2548</strong></td>
</tr>
</tbody>
</table>

# OF PANELS PER PROJECT

- Overall increase in # of braces is not proportional to the reduction in published capacity
- Implies brace insert capacity not being fully utilised – brace capacity is often the limiting factor
Thank you!