

An event of



BUILDING ENGINEERING SEMINAR 2025

Building Safer and Better **TOGETHER**

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Enhancing Safer Design

Essential Considerations for Post-Installed Reinforcement and Anchor Systems

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FALLING DEBRIS **KILLED PASSENGER** IN TUNNEL

Concrete panels fell from the ceiling of Boston's Big Dig highway project, killing a woman in a car near the entrance to the Ted Williams Tunnel.



- 1) Introduction
- 2) Qualifications
- 3) Design Considerations
- 4) Conclusion
- 5) Other Industry Collaboration



Introduction



Concrete Structure Connection

Cast-In (Pre-Installed)

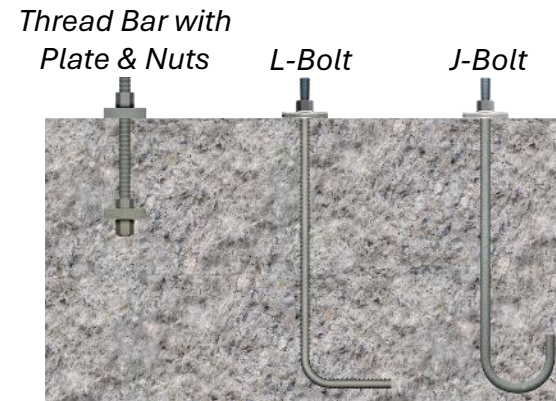
- Installed **before** concrete hardens
- Requires **precise positioning** during concrete placement



Cast-in reinforcement
(Starter bars)



Cast-in anchor bolts



Cast-in anchor bolts

Post-Installed

Focus of today's presentation

- Installed **after** concrete has hardened
- Provides **flexibility** in location

- Commonly used in **A&A works** and for **construction flexibility**

Post-Installed Reinforcement (PIR)

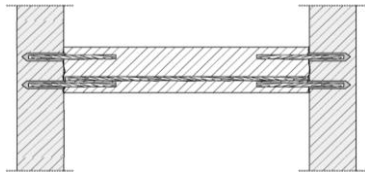


Photo credit: Hilti



Photo credit: Hilti

RC slab or beam onto an existing RC wall or column

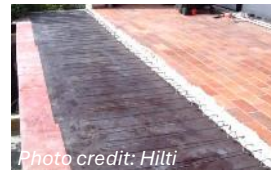
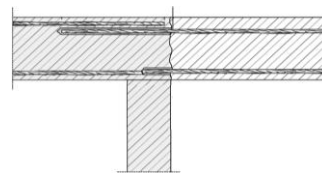


Photo credit: Hilti

Extending a RC slab or beam

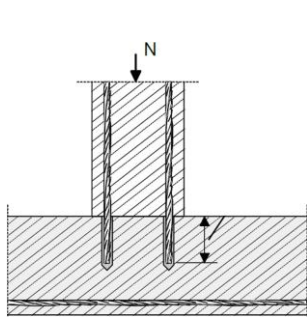


Photo credit: Hilti



Photo credit: Hilti

RC column or wall into the foundation



Photo credit: Hilti

Opening closure / slab enlargement

Post-Installed Anchor (PIA)



Photo credit: bavap.com.au

Steel column into the RC structure



Photo credit: newcivilengineer.com

Steel beam onto the RC structure



Photo credit: constructionspecifier.com

Railing installation



Photo credit: Hilti

Canopy support

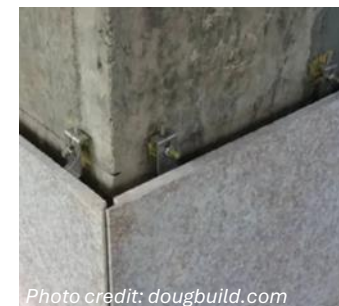
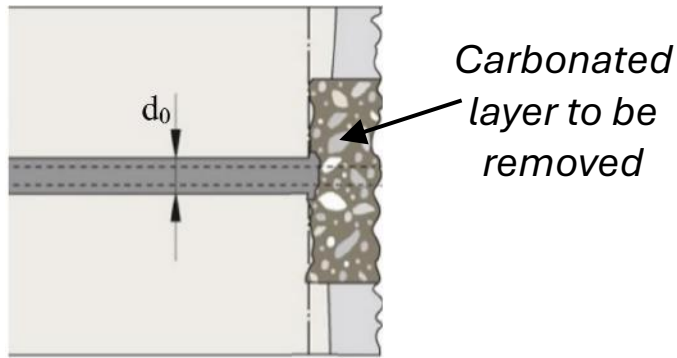


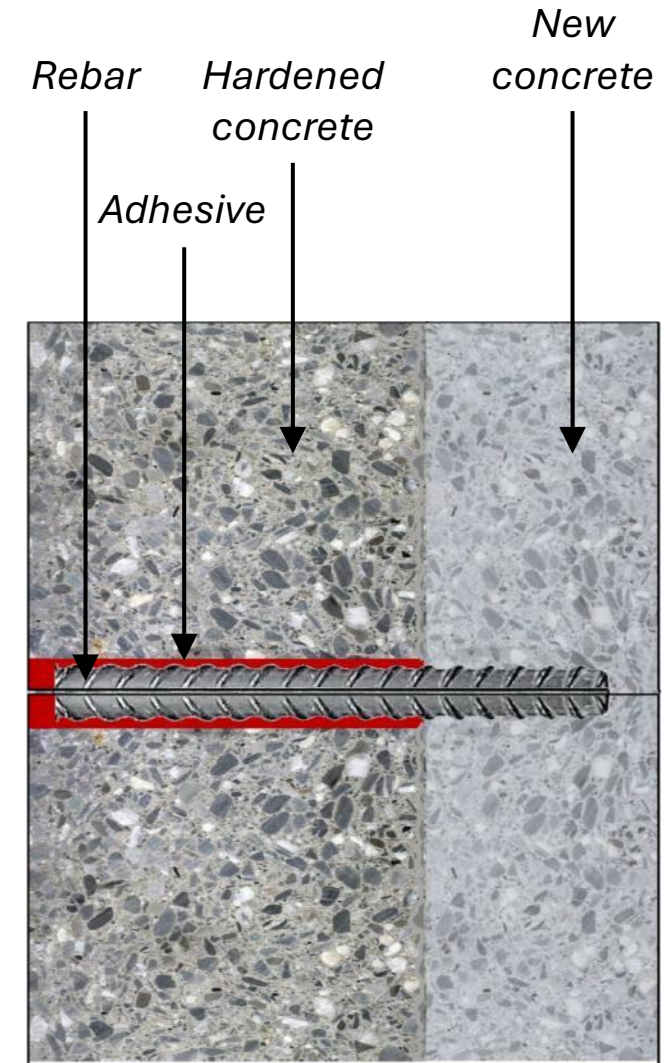
Photo credit: dougbuild.com

Façade attachment

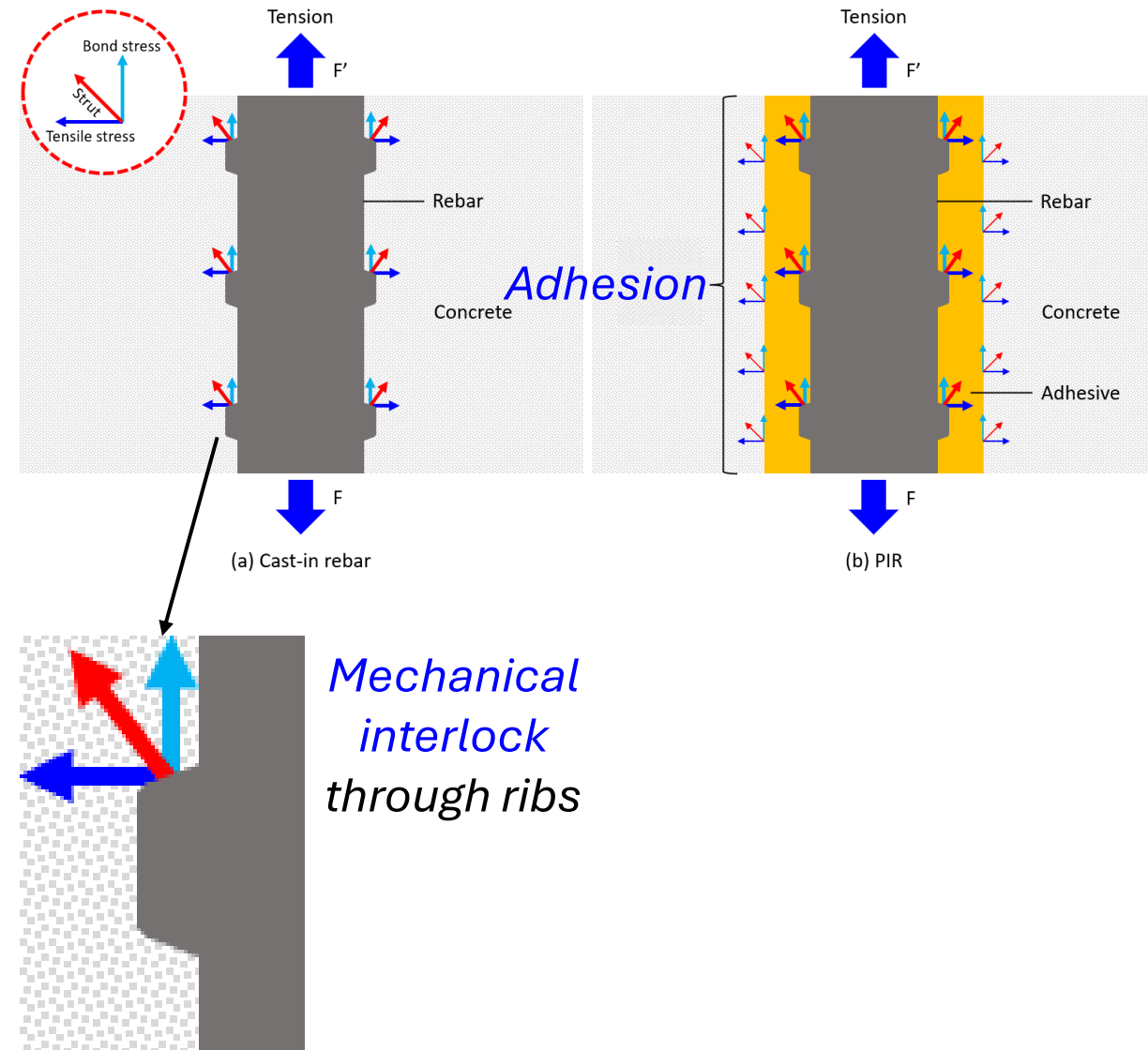
- **Post-installed reinforcement (PIR)** involves installing rebars into drilled holes in hardened concrete using adhesive
- The **adhesive must be qualified for PIR application**
- **Key requirements:**
 - Non-carbonated concrete only
 - Remove carbonated layer if present
 - No plain round bars



Plain round bars are not suitable for use in PIR system



- Load transfer occurs through:
 - Mechanical interlock between rebar ribs and adhesive
 - Adhesion between adhesive and concrete
- Performance depends on adhesive product
- Requires proper assessment and qualification

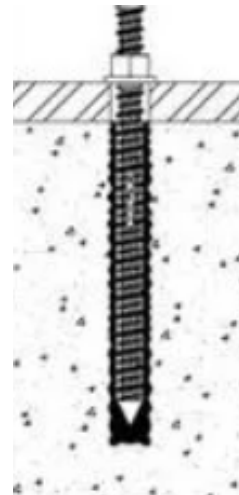
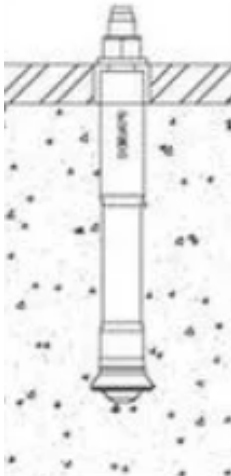


- **Post-installed anchor (PIA)** involves installing anchors into drilled holes in hardened concrete with/without adhesive
- Three main types of post-installed anchors:
 - **Mechanical anchors**
 - **Bonded anchors**
 - Combined mechanical and bonded anchors

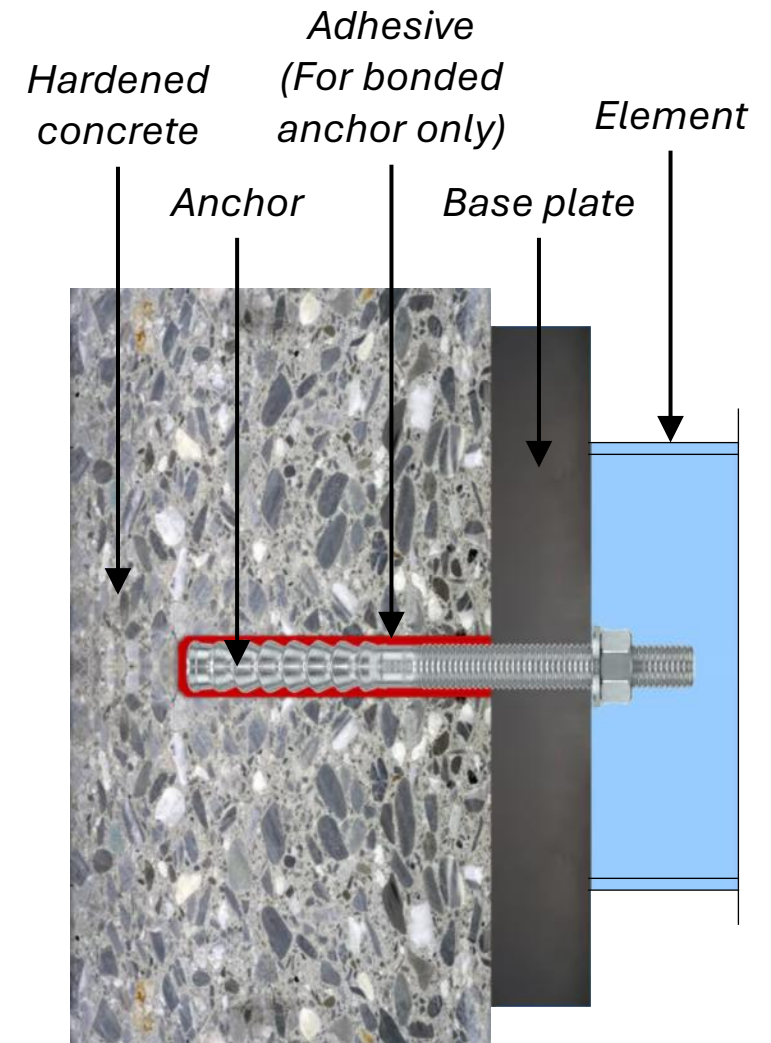
Common applications and focus of today's presentation for PIA



Mechanical anchor



Bonded anchor



Load transfer mechanisms based on anchor types:

1. Mechanical Anchors

Expansion anchors:

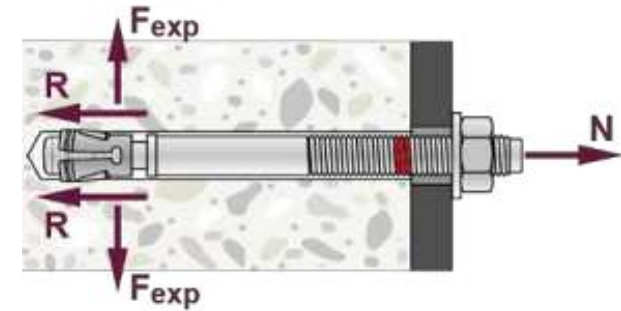
- Load transfer by **friction**
- Expansion force between anchor sleeve and concrete
- Most **common PIA proposed**

Undercut anchors:

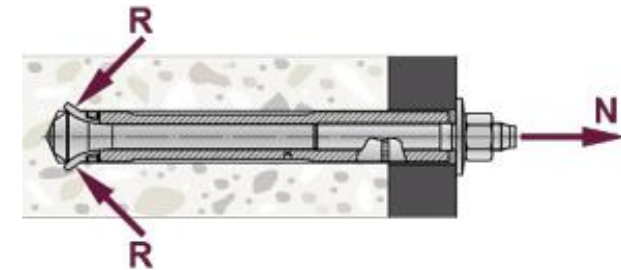
- Load transfer by **mechanical interlock**
- Bearing forces at the undercut in concrete

2. Bonded Anchors

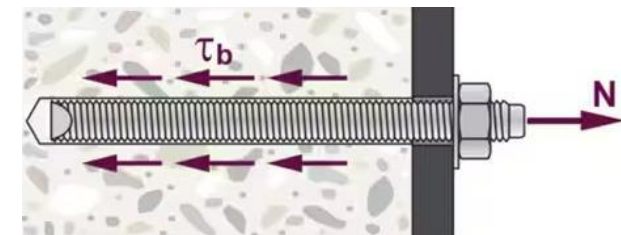
- Load transfer by **adhesion** between anchor, adhesive and concrete



Expansion anchor

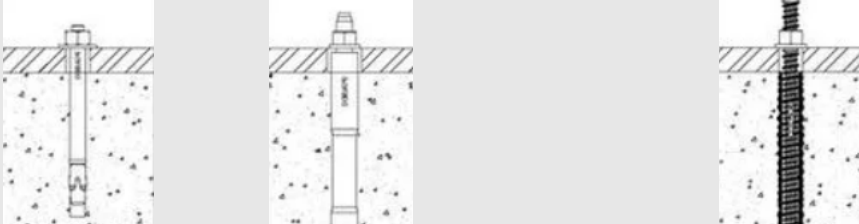
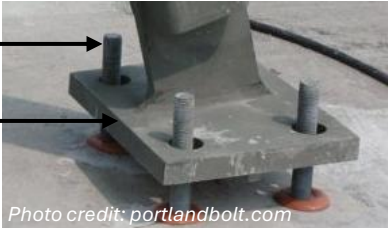


Undercut anchor



Bonded anchor

N – Tensile load
 R – Resistance
 F_{exp} – Expansion force
 τ_b – Bond strength

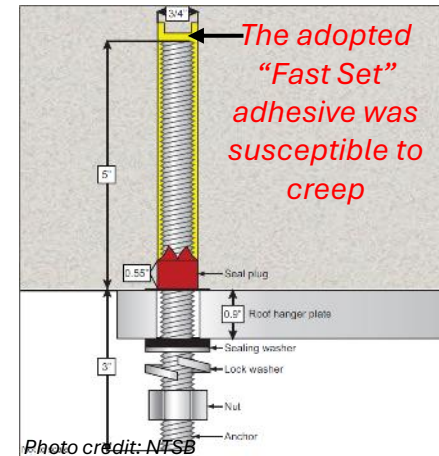
Aspect	Post-Installed Reinforcement (PIR)	Post-Installed Anchor (PIA)
Component	Adhesive + Reinforcement 	 Mechanical anchor (Expansion/undercut) Bonded anchor (Adhesive + Anchor element)
Connection Purpose	Concrete to concrete structural connection  Photo credit: horseen.com	Element to concrete connection  Photo credit: portlandbolt.com
Product Qualification	EAD 330087 – PIR EAD 332402 – PIR: Improved bond splitting	EAD 330232 – Mechanical fasteners EAD 330499 – Bonded fasteners EAD 330250 – Fasteners: Fatigue cyclic loading
Design Code	SS EN 1992-1-1 – Eurocode 2-1-1 SS EN 1992-1-2 – Eurocode 2-1-2 EOTA TR 069 – PIR: Improved bond splitting	SS EN 1992-4 – Eurocode 2-4 EOTA TR 061 – Fasteners: Fatigue cyclic loading EOTA TR 082 – Fasteners: Fire conditions (for bonded anchors)

Qualifications



Big Dig Tunnel Ceiling Collapse, Boston (2006)

- Ceiling panels collapsed due to **unsuitable bonded anchors**
- **Adhesive lacked creep resistance** for sustained loads
- Anchors pulled out due to **adhesive deformation over time**
- Demonstrates **importance of proper product qualification**

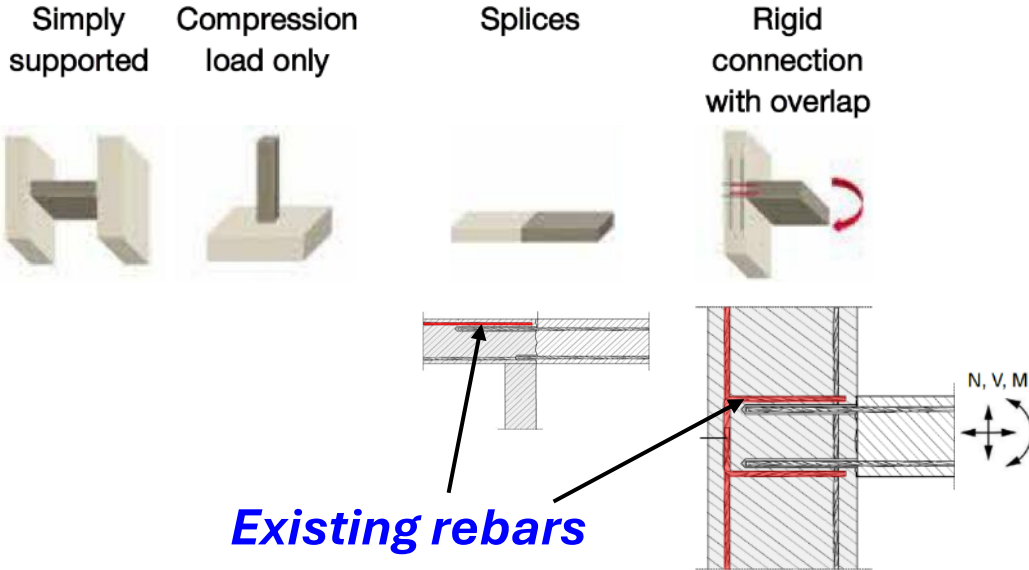
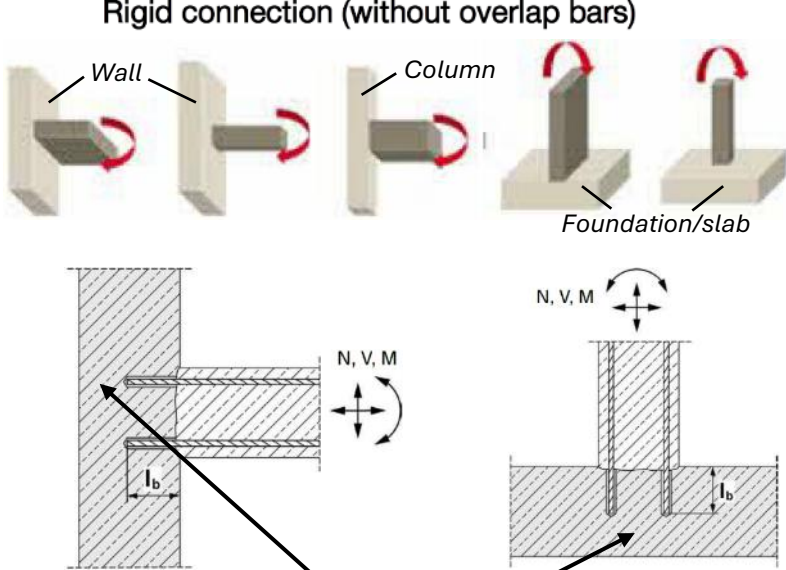


A significant number of anchors were found to have been affected



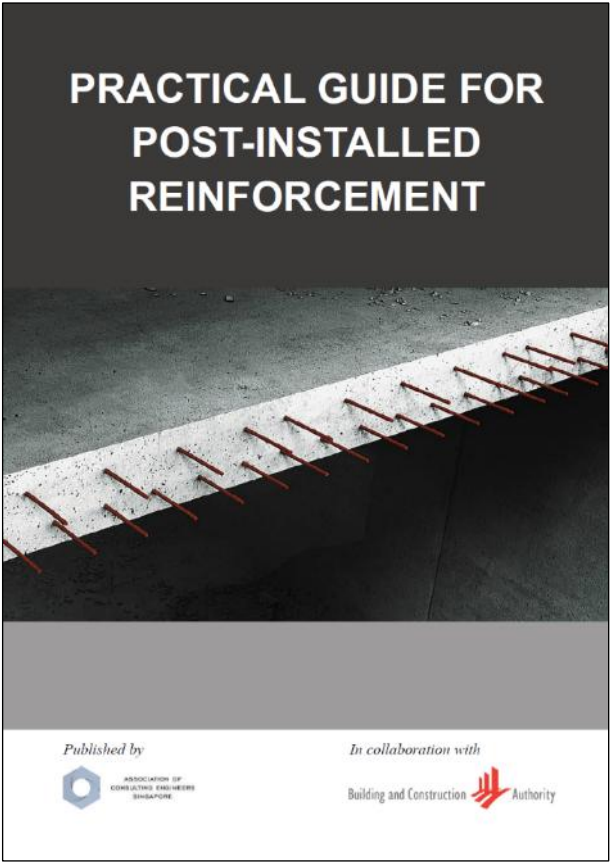


EAD – European Assessment Document
ETA – European Technical Assessment

	Static	Fire	Seismic	Static	Seismic
Qualification	EAD 330087 (“ Basic ” qualification)			EAD 332402 (“ Advance ” qualification)	
Design method	Eurocode EC2-1-1, EC2-1-2, EC8			EOTA TR 069	
Limitation	- Fatigue loading is not covered - Seismic and fire assessments are optional			Fatigue loading and fire are not covered	
	Simply supported Compression load only Splices Rigid connection with overlap  Existing rebar for lapping			Rigid connection (without overlap bars)  No need existing rebar for lapping	



<https://go.gov.sg/pir-guide>



The guide covers everything you need to know about PIR:

- Qualification
- Design
- Installation
- Quality control

Site Testing

Table 7. Recommended frequency for on-site testing, modified from NA to SS EN 1992-4.

No. of PIR installed (n*)	Test frequency (rounded up)
1-1000	n x 2.5% or 3 nos (whichever is greater)
1001-5000	25 nos + (n-1000) x 1.0%
5001 and above	65 nos + (n-5000) x 0.2%

*n is the number of PIR to be installed in any discrete area as defined in BS 8539, Annex B.3.

Fire Design

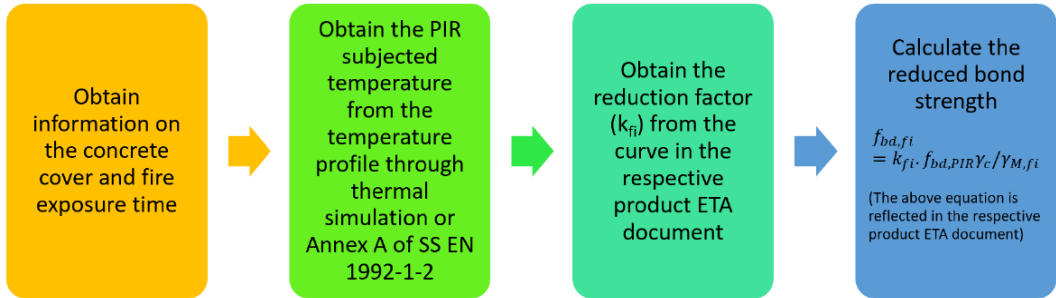
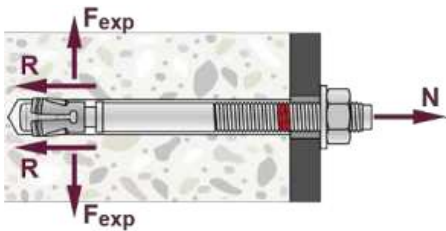


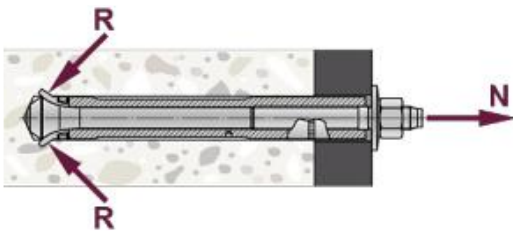
Figure 5. Steps to obtain the reduced bond strength for PIR due to fire exposure



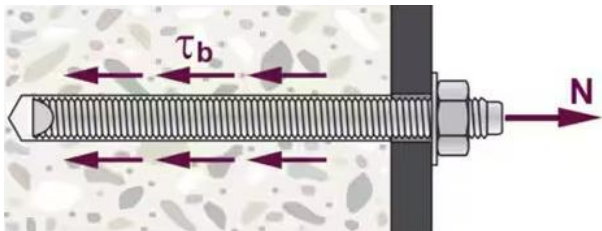
	Mechanical Anchors				Bonded Anchors			
	Static	Seismic	Fire	Fatigue	Static	Seismic	Fire	Fatigue
Qualification	EAD 330232			EAD 330250	EAD 330499			EAD 330250
Design method	Eurocode EC2-4			EOTA TR 061	Eurocode EC2-4		EOTA TR 082	EOTA TR 061
Limitation	Seismic, fire, and concrete condition assessment is optional							



Expansion anchor



Undercut anchor



Bonded anchor



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Technical Assessment Body (TAB)

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European Technical Assessment

ETA-20/0540 **ETA Number**
dated 13/12/2023

English translation prepared by CSTB - Original version in French language

General Part

Technical Assessment Body issuing the European Technical Assessment:
Centre Scientifique et Technique du Bâtiment (CSTB)

Trade name: **Injection system PRODUCT ABCD for rebar connection**

Product family: **Post installed rebar connections diameter 8 to 40 mm made with PRODUCT ABCD injection mortar for a working life of 100 years**

Manufacturer: **Product Name**

Manufacturing plants:

This European Technical Assessment contains: **33 pages including 30 pages of annexes which form an integral part of this assessment**

This European Technical Assessment is issued in accordance with Regulation (EU) No 305/2011, on the basis of: **EAD 330087-01-0601** **Qualified EAD**

Design Values:

Essential characteristics under static and quasi-static loading

Minimum anchorage length, minimum lap length and design values of the bond strength for a working life of 50 and 100 years for diamond coring (wet).

The minimum anchorage length $l_{b,min}$ and the minimum lap length $l_{o,min}$ according to EN 1992-1-1 shall be multiplied by the amplification factor $\alpha_{lb} = \alpha_{lb,100y}$ given in Table C4.

The design values of the bond strength $f_{bd,PIR}$ and $f_{bd,PIR,100y}$ are given in Table C6. It is obtained by multiplying the design value of the bond strength f_{bd} according to EN 1992-1-1 (Eq. 8.3) by the bond efficiency factor $k_b = k_{b,100y}$ according to Table C5.

Table C4: Amplification factor α_{lb} and $\alpha_{lb,100y}$

Rebar diameter	Amplification factor $\alpha_{lb} = \alpha_{lb,100y}$ [-]								
	Concrete class								
	C12/15	C16/20	C20/25	C25/30	C30/37	C35/45	C40/50	C45/55	C50/60
φ 8 to φ 12	1,0								
φ 13 to φ 36	Linear interpolation between diameters								
φ 40	1,0			1,2	1,3	1,4			

Table C5: Bond efficiency factor k_b and $k_{b,100y}$

Rebar diameter	Bond efficiency factor $k_b = k_{b,100y}$ [-]								
	Concrete class								
	C12/15	C16/20	C20/25	C25/30	C30/37	C35/45	C40/50	C45/55	C50/60
φ 8 to φ 12	1,0								0,93
φ 13 and φ 16	1,0							0,93	0,86
φ 18 to φ 36	1,0						0,92	0,85	0,79
φ 40	1,0				0,90	0,82	0,76	0,71	

Table C6: Design values of the bond strength $f_{bd,PIR}^{(1)}$ and $f_{bd,PIR,100y}^{(1)}$

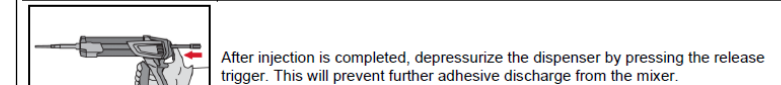
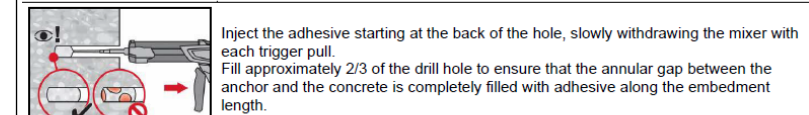
Rebar diameter	Bond strength $f_{bd,PIR} = f_{bd,PIR,100y}$ [N/mm ²]								
	Concrete class								
	C12/15	C16/20	C20/25	C25/30	C30/37	C35/45	C40/50	C45/55	C50/60
φ 8 to φ 12	1,6	2,0	2,3	2,7	3,0	3,4	3,7	4,0	4,0
φ 13 and φ 16	1,6	2,0	2,3	2,7	3,0	3,4	3,7	3,7	3,7
φ 18 to φ 32	1,6	2,0	2,3	2,7	3,0	3,4	3,4	3,4	3,4
φ 34	1,6	2,0	2,3	2,6	2,9	3,3	3,3	3,3	3,3
φ 36	1,6	1,9	2,2	2,6	2,9	3,2	3,2	3,2	3,2
φ 40	1,5	1,8	2,1	2,5	2,8	2,8	2,8	2,8	2,8

¹⁾ According to EN 1992-1-1 for good bond conditions. For all other bond conditions multiply the values by 0,7.

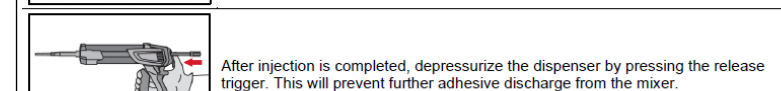
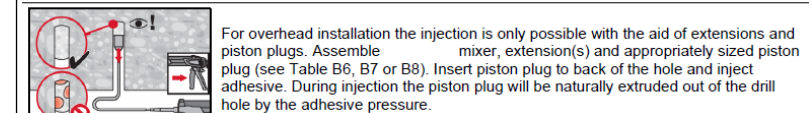
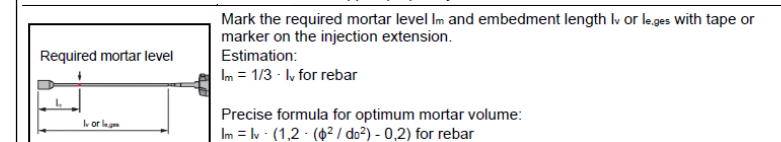
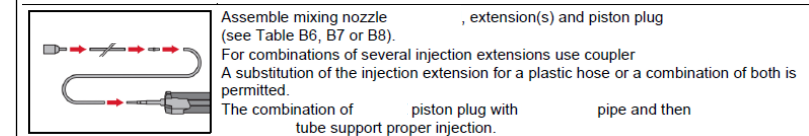
Installation Procedures:

Inject adhesive: inject adhesive from the back of the drill hole without forming air voids.

Injection method for drill hole depths ≤ 250 mm (without overhead applications)



Injection method for drill hole depths > 250 mm or overhead applications



Usage Limitations

(Note: Seismic, fire, and uncracked/cracked concrete assessment are optional in the EAD)

Product A

3 Performance of the product and references to the methods used for its assessment

3.1 Mechanical resistance and stability (BWR 1)

Essential characteristic	Performance
Characteristic resistance under static and quasi-static loading	See Annex C 1 to C 3
Characteristic resistance under seismic loading	See Annex B 4 and C 4

Static: ✓

Seismic: ✓

3.2 Safety in case of fire (BWR 2)

Essential characteristic	Performance
Reaction to fire	Class A1
Resistance to fire	See Annex C 5

Fire: ✓

Product B

3 Performance of the product and references to the methods used for its assessment

3.1 Performance of the product

3.1.1 Mechanical resistance and stability (BWR 1)

Essential characteristic	Performance
Characteristic resistance under static and quasi-static loading	See Annex C

Static: ✓

Seismic: X

3.1.2 Safety in case of fire (BWR 2)

Essential characteristic	Performance
Reaction to fire	The post-installed rebar connection satisfies requirements for Class A1
Resistance to fire	No performance assessed

Fire: X

Product A

Essential characteristics under static loading

Minimum anchorage length, minimum lap length and design values of the bond strength for a working life of 50 and 100 years for following drilling techniques:

The minimum anchorage length $l_{a,min}$ and the minimum lap length $l_{l,min}$ according to EN 1992-1-1 shall be multiplied by the amplification factor $\alpha_{ls} = \alpha_{ls,100y}$ given in Table C1.
The design values of the bond strength $f_{bd,PR}$ and $f_{bd,PR,100y}$ are given in Table C3. It is obtained by multiplying the design value of the bond strength f_{bd} according to EN 1992-1-1 (Eq. 8.3) by the bond efficiency factor $k_b = k_{b,100y}$ according to Table C2.

Table C1: Amplification factor α_{ls} and $\alpha_{ls,100y}$

Rebar diameter	Amplification factor $\alpha_{ls} = \alpha_{ls,100y}$ [-]							
	Concrete class							
Ø 8 to Ø 40	C12/15	C16/20	C20/25	C25/30	C30/37	C35/45	C40/50	C45/55

Table C2: Bond efficiency factor k_b and $k_{b,100y}$

Rebar diameter	Bond efficiency factor $k_b = k_{b,100y}$ [-]							
	Concrete class							
Ø 8 to Ø 40	C12/15	C16/20	C20/25	C25/30	C30/37	C35/45	C40/50	C45/55

Table C3: Design values of the bond strength $f_{bd,PR}^{(1)}$ and $f_{bd,PR,100y}^{(1)}$

Rebar diameter	Bond strength $f_{bd,PR} = f_{bd,PR,100y}$ [N/mm ²]							
	Concrete class							
Ø 8 to Ø 32	C12/15	C16/20	C20/25	C25/30	C30/37	C35/45	C40/50	C45/55
Ø 34								
Ø 36								
Ø 40								

⁽¹⁾ According to EN 1992-1-1 for good bond conditions. For all other bond conditions multiply the values by 0.7.

For C50/60 and Ø40,
PIR bond strength ($f_{bd,PR}$) = 3.9N/mm²

Performance
Essential characteristics under static and quasi-static loading

Annex C1

Design values
for static condition

Essential characteristics under seismic loading

Minimum anchorage length, minimum lap length and design values of the bond strength for a working life of 50 and 100 years for following drilling techniques:

The minimum anchorage length $l_{a,min}$ and the minimum lap length $l_{l,min}$ according to EN 1992-1-1 shall be multiplied by the relevant amplification factor $\alpha_{ls} = \alpha_{ls,100y}$ given in Table C9.
The design values of the bond strength $f_{bd,PR,seis}$ and $f_{bd,PR,seis,100y}$ are given in Table C11. It is obtained by multiplying the design value of the bond strength f_{bd} according to EN 1992-1-1 (Eq. 8.3) by the seismic bond efficiency factor $k_{b,seis} = k_{b,seis,100y}$ according to Table C10.
The minimum concrete cover below the value according to Table B3 and $c_{min,seis} = 2 \phi$ applies.

Table C9: Amplification factor α_{ls} and $\alpha_{ls,100y}$

Rebar diameter	Amplification factor $\alpha_{ls} = \alpha_{ls,100y}$ [-]							
	Concrete class							
Ø 8 to Ø 40	C16/20	C20/25	C25/30	C30/37	C35/45	C40/50	C45/55	C50/60

Table C10: Seismic bond efficiency factor $k_{b,seis}$ and $k_{b,seis,100y}$

Rebar diameter	Seismic bond efficiency factor $k_{b,seis} = k_{b,seis,100y}$ [-]							
	Concrete class							
Ø 8 to Ø 40	C16/20	C20/25	C25/30	C30/37	C35/45	C40/50	C45/55	C50/60

Table C11: Design values of the bond strength $f_{bd,PR,seis}^{(1)}$ and $f_{bd,PR,seis,100y}^{(1)}$

Rebar diameter	Bond strength $f_{bd,PR,seis} = f_{bd,PR,seis,100y}$ [N/mm ²]							
	Concrete class							
Ø 8 to Ø 32	C16/20	C20/25	C25/30	C30/37	C35/45	C40/50	C45/55	C50/60
Ø 34								
Ø 36								
Ø 40								

⁽¹⁾ According to EN 1992-1-1 for good bond conditions. For all other bond conditions multiply the values by 0.7.

Performance
Essential characteristics under seismic loading

Annex C4

Design values
for seismic condition

Essential characteristics under fire exposure

Design value of the bond strength f_{bd} for a working life of 50 years and design value of the bond strength $f_{bd,100y}$ for a working life of 100 years under fire exposure for concrete classes C12/15 to C50/60 for all drilling techniques.

The design values of the bond strength f_{bd} and $f_{bd,100y}$ under fire exposure have to be calculated by the following equation:

$$f_{bd,fi} = k_{s,fi}(\theta) \cdot f_{bd,PR} \cdot \frac{Y_{fi}}{Y_{m,fi}}$$

for a working life of 50 years

$$f_{bd,fi,100y} = k_{s,fi,100y}(\theta) \cdot f_{bd,PR,100y} \cdot \frac{Y_{fi}}{Y_{m,fi}}$$

for a working life of 100 years

$$k_{s,fi}(\theta) = \frac{651.24 \cdot \theta^{-1.118}}{f_{bd,PR}} \leq 1.0$$

for a working life of 50 years

$$k_{s,fi,100y}(\theta) = \frac{651.24 \cdot \theta^{-1.118}}{f_{bd,PR,100y}} \leq 1.0$$

for a working life of 100 years

$$\theta > 305^\circ\text{C}: k_{s,fi}(\theta) = k_{s,fi,100y}(\theta) = 0.0$$

$f_{bd,fi}$: Design value of the bond strength in case of fire in N/mm² for a working life of 50 years.

$f_{bd,fi,100y}$: Design value of the bond strength in case of fire in N/mm² for a working life of 100 years.

θ : Temperature in °C in the mortar layer.

$k_{s,fi}(\theta)$: Reduction factor under fire exposure for a working life of 50 years.

$k_{s,fi,100y}(\theta)$: Reduction factor under fire exposure for a working life of 100 years.

$f_{bd,PR}$: Design value of the bond strength in N/mm² in cold condition according to Table C3 or Table C5 considering the concrete classes, the rebar diameter, the drilling method and the bond conditions according to EN 1992-1-1 for a working life of 50 years.

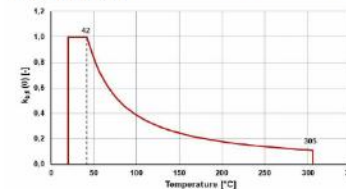
$f_{bd,PR,100y}$: Design value of the bond strength in N/mm² in cold condition according to Table C3 or Table C5 considering the concrete classes, the rebar diameter, the drilling method and the bond conditions according to EN 1992-1-1 for a working life of 100 years.

Y_{fi} : Partial factor according to EN 1992-1-1.

$Y_{m,fi}$: Partial factor according to EN 1992-1-2.

For evidence under fire exposure the anchorage length shall be calculated according to EN 1992-1-1:2004+AC:2010 Equation 8.3 using the temperature-dependent bond strength f_{bd} .

Figure C1: Example graph of temperature reduction factor $k_{s,fi}(\theta)$ for concrete class C20/25 for good bond conditions



Performance
Essential characteristics under fire exposure

Annex C

Design values
for fire condition

Product B

Design bond strength of post-installed rebar $f_{bd,PR}$ and $f_{bd,PR,100y}$ for working life 50 and 100 years

$f_{bd,PR} = k_b \cdot f_{bd}$
 k_b = reduction factor
 f_{bd} = design bond strength of cast-in rebar according to EN 1992-1-1

Table C1: Values of the design bond strength of post installed rebar $f_{bd,PR}$ for all drilling methods for good bond conditions

Concrete class	Rebar Ø 8 to Ø 14							
	C12/15	C16/20	C20/25	C25/30	C30/37	C35/45	C40/50	C45/55
k_b	1,0	1,0	1,0	1,0	1,0	1,0	1,0	0,92
$f_{bd,PR}$ [N/mm ²]	1,6	2,0	2,3	2,7	3,0	3,4	3,7	3,7

Concrete class	Rebar Ø 16							
	C12/15	C16/20	C20/25	C25/30	C30/37	C35/45	C40/50	C45/55
k_b	1,0	1,0	1,0	1,0	1,0	1,0	1,0	0,92
$f_{bd,PR}$ [N/mm ²]	1,6	2,0	2,3	2,7	3,0	3,4	3,7	4,0

Concrete class	Rebar Ø 20 to Ø 26							
	C12/15	C16/20	C20/25	C25/30	C30/37	C35/45	C40/50	C45/55
k_b	1,0	1,0	1,0	1,0	1,0	1,0	1,0	0,93
$f_{bd,PR}$ [N/mm ²]	1,6	2,0	2,3	2,7	3,0	3,4	3,7	4,0

Concrete class	Rebar Ø 28							
	C12/15	C16/20	C20/25	C25/30	C30/37	C35/45	C40/50	C45/55
k_b	1,0	1,0	1,0	1,0	1,0	1,0	1,0	0,86
$f_{bd,PR}$ [N/mm ²]	1,6	2,0	2,3	2,7	3,0	3,4	3,7	3,7

Concrete class	Rebar Ø 32							
	C12/15	C16/20	C20/25	C25/30	C30/37	C35/45	C40/50	C45/55
k_b	1,0	1,0	1,0	1,0	0,88	0,90	0,92	0,76
$f_{bd,PR}$ [N/mm ²]	1,6	2,0	2,3	2,7	2,7	3,0	3,4	3,0

Concrete class	Rebar Ø 40							
	C12/15	C16/20	C20/25	C25/30	C30/37	C35/45	C40/50	C45/55
k_b	1,0	0,82	0,71	0,61	0,64	0,48	0,44	0,41
$f_{bd,PR}$ [N/mm ²]	1,6	2,0	2,3	2,7	2,7	2,7	2,7	2,7

Tabulated values are valid for good bond conditions according to EN 1992-1-1. For all other bond conditions multiply the values by 0.7.

Table C2: Amplification factor for minimum anchorage length for all drilling methods

Rebar	Amplification factor	Concrete class C12/15 to C50/60
Ø 8 to Ø 40	$\alpha_{ls} = \alpha_{ls,100y}$	1,5

For C50/60 and Ø40,
PIR bond strength ($f_{bd,PR}$) = 1.5N/mm²

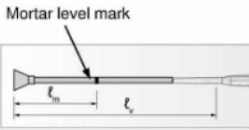
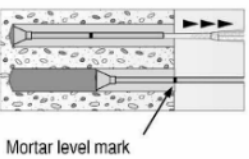
Performances
Design values of the ultimate bond resistance for hammer drilling

Annex C

Design values
for static condition

No products are equivalent

ETA Installation Requirements:

Injection of the mortar; borehole depth > 250 mm	
	Assemble mixing nozzle and appropriate injection adapter (see table B 6.2) extension tube and
	Mark the required mortar level l_m and embedment depth l_v resp. $l_{e,ges}$ with tape or marker on the injection extension tube. a) Estimation: $l_m = \frac{1}{3} * l_v \text{ resp. } l_m = \frac{1}{3} * l_{e,ges} \text{ [mm]}$ b) Precise equation for optimum mortar volume: $l_m = l_v \text{ resp. } l_{e,ges} \left((1,2 * \frac{d_v^2}{d_g^2} - 0,2) \right) \text{ [mm]}$
	Insert injection adapter to back of the hole. Begin injection allowing the pressure of the injected adhesive mortar to push the injection adapter towards the front of the hole. Do not actively pull out! Fill holes approximately 2/3 full, to ensure that the annular gap between the rebar and the concrete will be completely filled with adhesive over the embedment length. When using an injection adapter continue injection until the mortar level mark l_m becomes visible. Maximum embedment depth see table B5.2
	After injecting, release the dispenser. This will prevent further mortar discharge from the mixing nozzle.

Extension tube required: holes > 250mm



Photo credit: BCA

Extension tube



Photo credit: BCA

- Use extension tube
- Fill hole **completely** with adhesive

- No extension tube
- Fill hole **incompletely** with adhesive

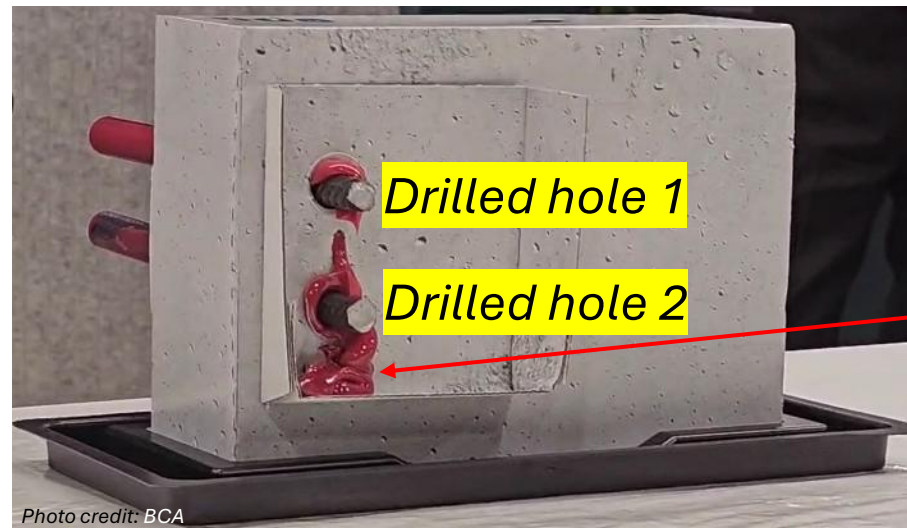


Photo credit: BCA

Adhesive overflow ≠ hole completely filled!

Design Considerations



- **Tension connection:**
 - High-risk and not preferred
 - Brittle failure without warning
 - Can lead to catastrophic collapse
- **Shear connection:**
 - Preferred for better robustness

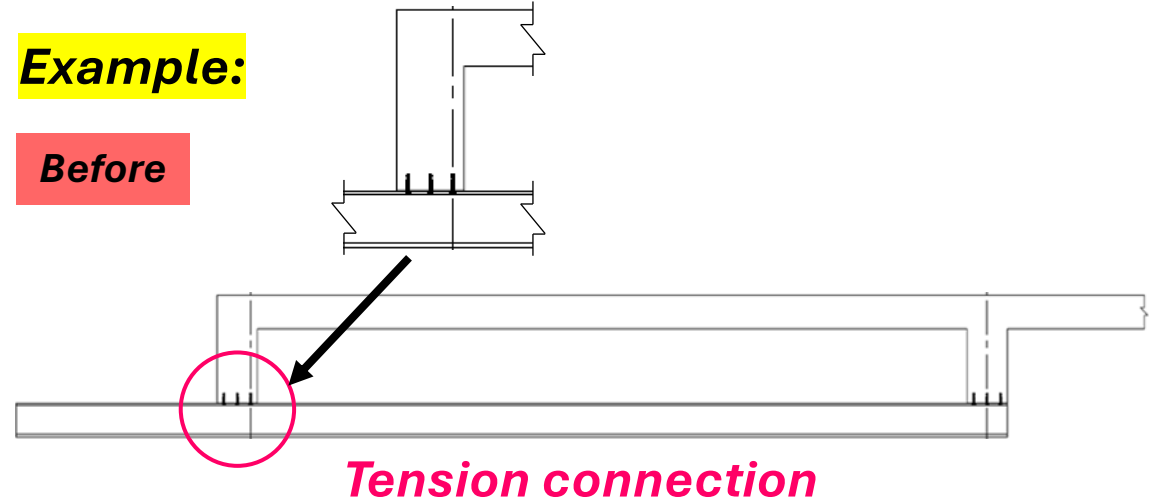


Photo credit: CNN

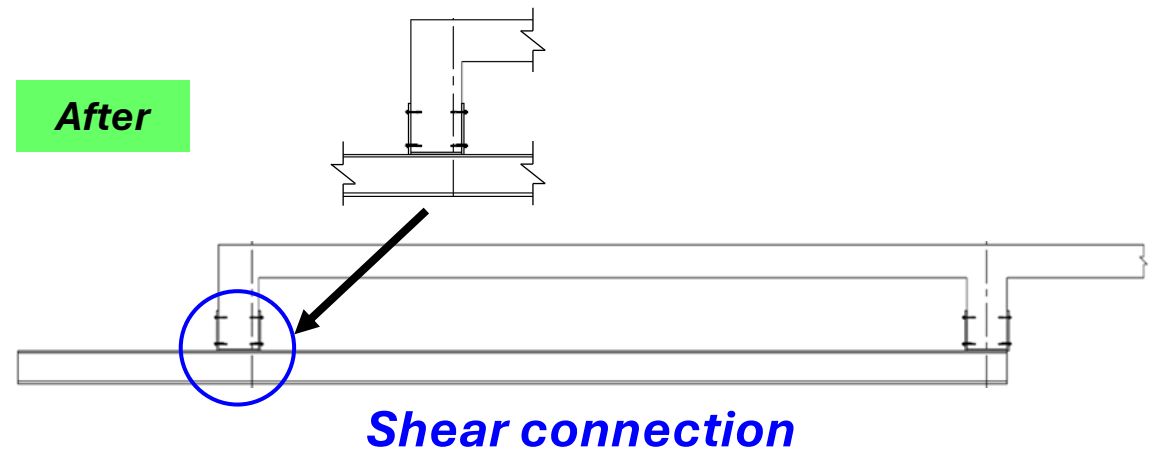
Indonesia Stock Exchange building

Example:

Before



After



- Loads are uncertain and difficult to quantify
- BS 8539 Clause 5.2(c): requirements for robustness
- Prefer cast-in connections over post-installed connections

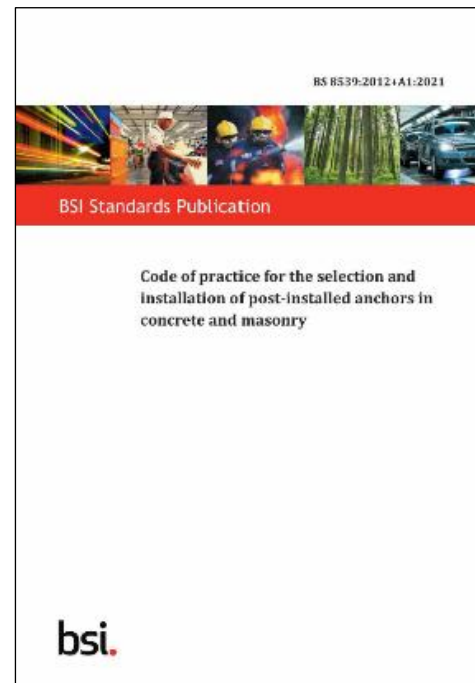


Photo credit: BCA

Redundancy shall be considered for tension connections
(e.g. **tension member failure scenarios, higher safety factors**)

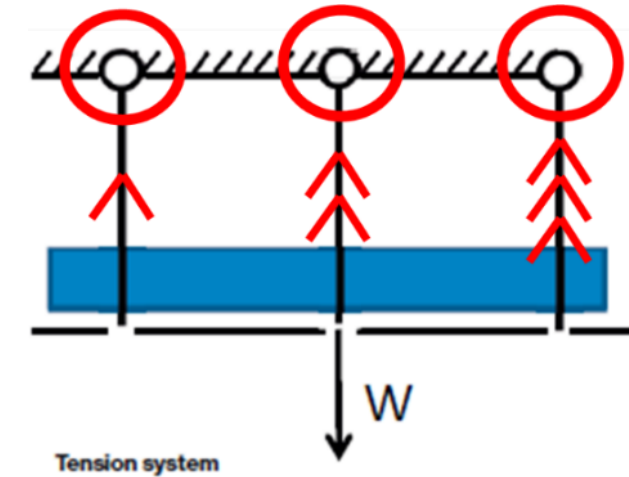
BS 8539:2012+A1:2021

'Code of practice for the selection and installation of post-installed anchors in concrete and masonry'



IStructE Publication

'Safety of hanging systems: lessons from CROSS reports'



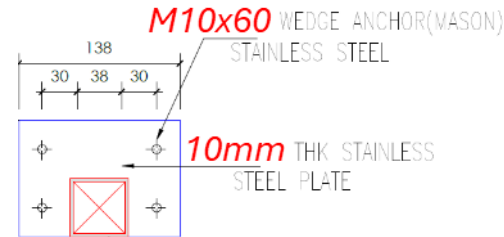
Tension system

- Connection design governed by forces and moments from assumed loading
- Use conservative loading for robustness
- Ensure proper lever arm consideration

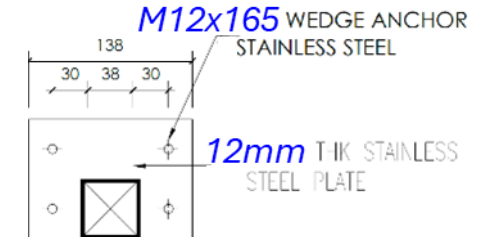
Example 1:

Horizontal load for barrier incorrectly adopted as **1.5kN/m** instead of required **3.0kN/m**

Before



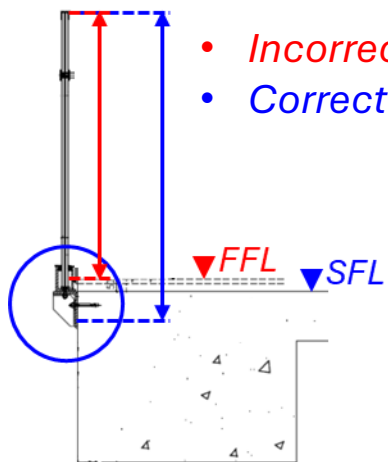
After



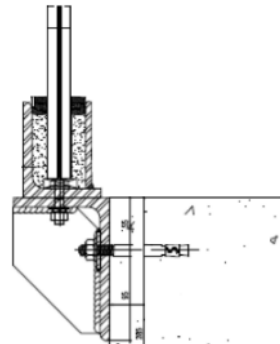
Be aware of areas where overcrowding is possible

Example 2:

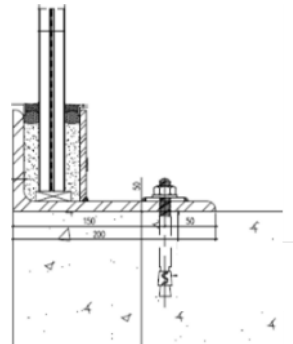
Lever arm for bending moment derivation was wrongly adopted



Before



After



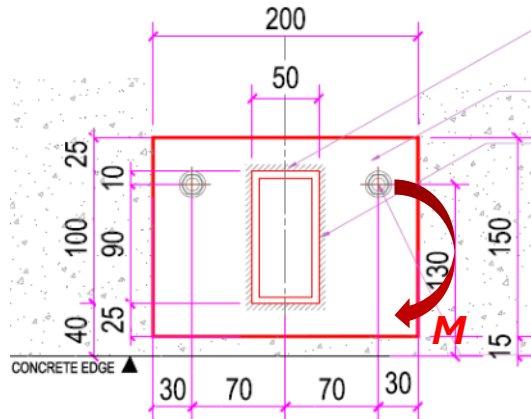
Collapsed railing incident at Bolivia university

- Influences the design forces for moment connections
- Provide the largest possible lever arms
- Use two or more anchor rows for moment connections

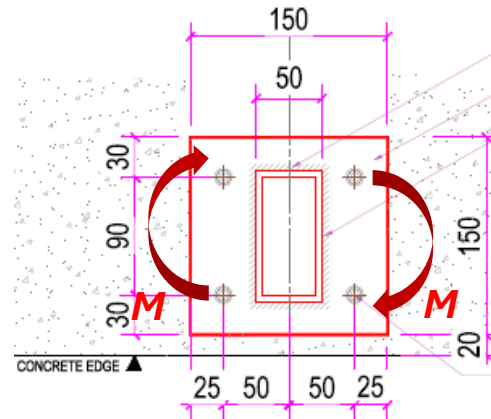
Example:

Only considered
bending moment in **one**
direction

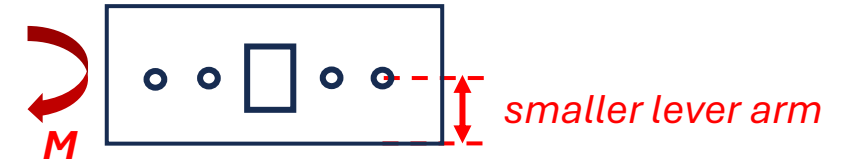
Before



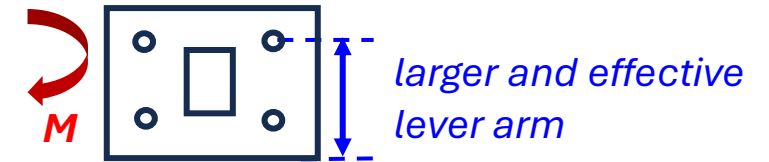
After



Poor Arrangement



Good Arrangement

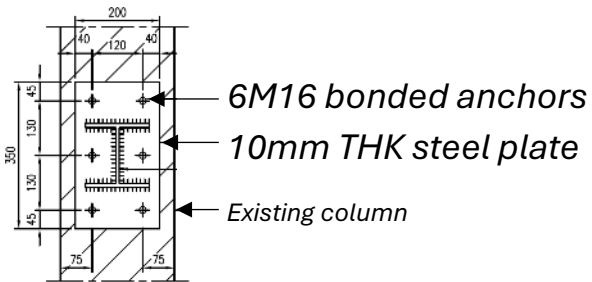


- Influences distribution of anchor force
- Evaluate based on actual base plate stiffness
- Provide stiffeners to achieve rigid base plate behaviour

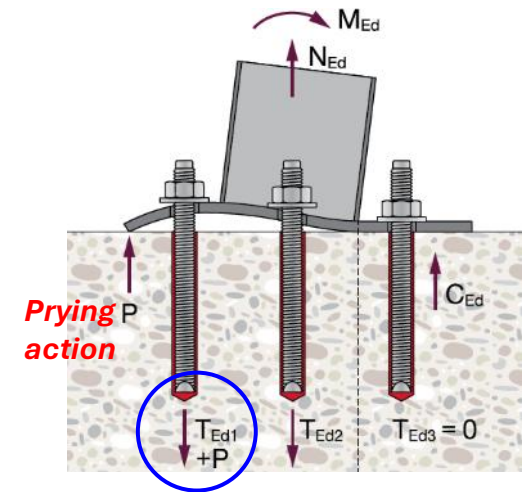
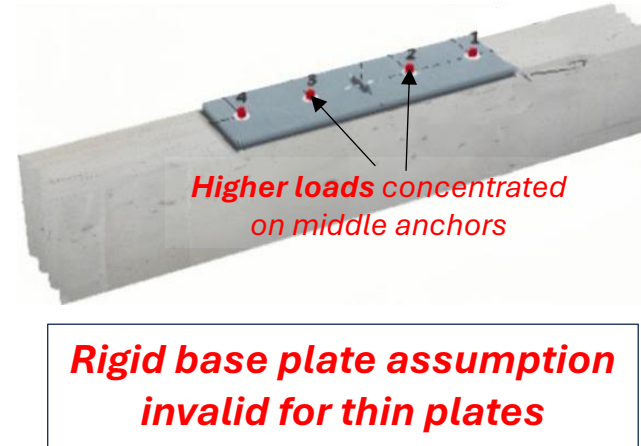
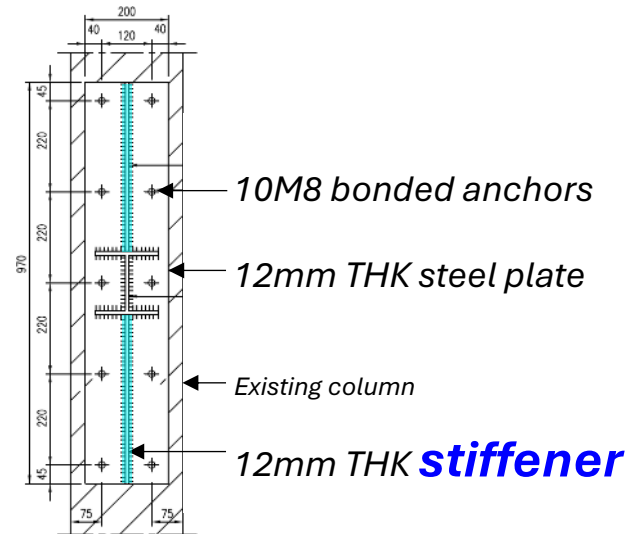
Example:

Before

Load distribution not evaluated in thin plates



After



Additional tensile forces due to prying action

- Crucial for anchor service life performance
- Refer to BS 8539 Table 1 for guidance
- Cladding fixings: corrosion-resistant stainless steel anchors (BS EN ISO 3506)

BS 8539:2012+A1:2021

Table 1 Anchor materials used to minimize the risk of corrosion

Application condition	Anchor materials for required duration ^{A), B)}		
	Short term	Medium term	Long term
Dry internal	FE-Zn	FE-Zn	FE-Zn
Internal humid, no chlorides, or acid condensates	FE-Zn	HDG +	SS A2 SS D2
External – rural, urban, light industrial areas with light/modest pollution. Internal permanently damp	HDG +	HDG +	SS A2 SS D2
External ^{C)} – industrial or coastal but not immersed or splash zone, see special applications	HDG +	SS A4 SS D4	SS A4 SS A5 SS D4 SS D6
Special applications ^{D)}	Special alloys of stainless steel		

^{A)} Approximate duration:

- short term = ≤2 years;
- medium term = ≤10 years;
- long term = ≤50 years.

Stainless steel anchors
should be provided for
permanent structures



Inappropriate anchor material led to corrosion and failure



- Concrete cracks due to bending, shear, creep and shrinkage effects
- Design for cracked concrete condition unless zero tensile stress can be proven (SS EN 1992-4 Eq 4.4)
- Verify product qualification for use in cracked concrete

ETA of **Product A**

Specifications of intended use

- Anchorage subject to:
- Static and quasi static loading.

Base materials:

- Compacted reinforced or unreinforced normal weight concrete without fibres according to EN 206:2013+A1:2016.
- Strength classes C20/25 to C50/60 according to EN 206:2013+A1:2016.
- uncracked concrete.

*Qualified for uncracked
concrete only*

ETA of **Product B**

Specifications of intended use

Anchorage subject to:

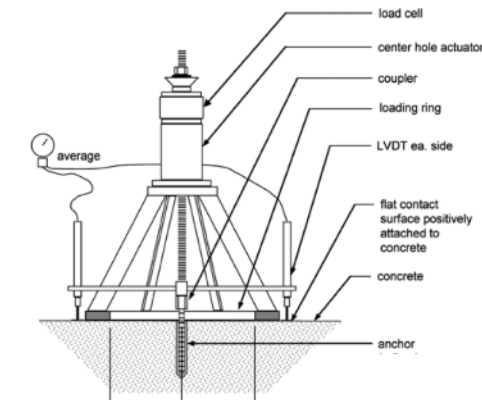
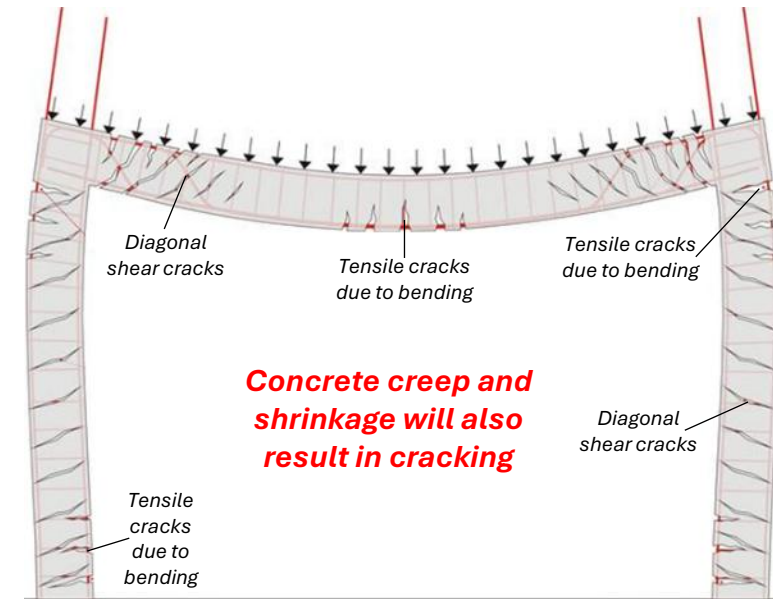
- Static and quasi-static loading: all sizes.
- Seismic performance category C1 and C2: all sizes.
- Fire exposure: all sizes.

Base materials:

- Reinforced or unreinforced normal weight concrete according to EN 206:2013+ A1:2016.
- Strength classes C20/25 to C50/60 according to EN 206:2013+A1:2016.
- Cracked and uncracked concrete.

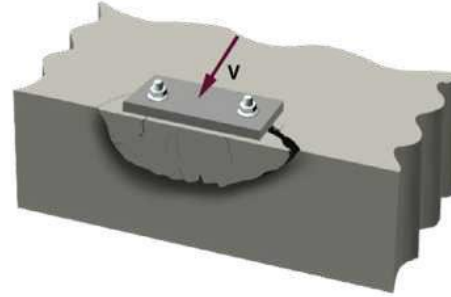
*Qualified for cracked
and uncracked concrete*

Not all post-installed connections are qualified for use in cracked concrete

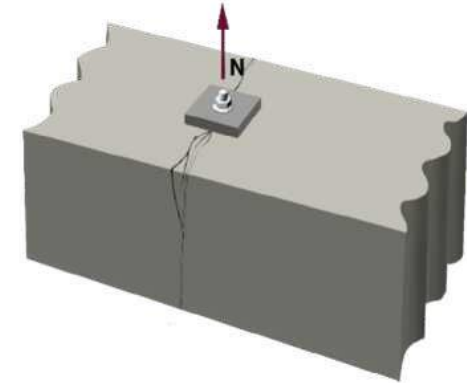


*Crack cycling test:
Optional assessment in EAD*

- Insufficient edge distance may result in **concrete edge breakout** and **splitting failures**
- **Edge distance** is a critical design parameter that **governs connection capacity**



Concrete edge breakout



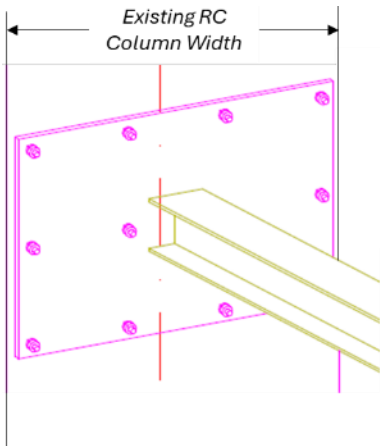
Splitting failure



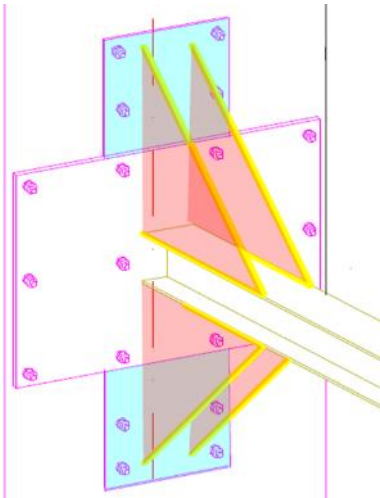
Example 1:

Before

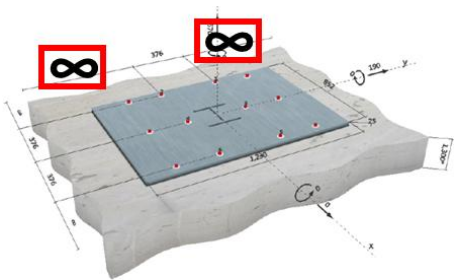
Edge distance was overlooked in the design of moment connection



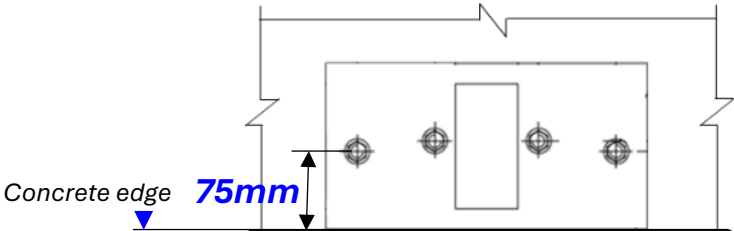
After



QP calculation:

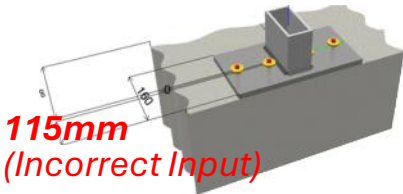


Example 2:



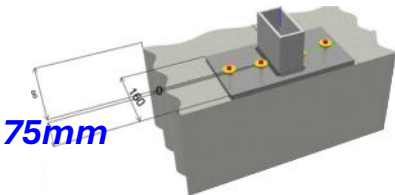
Incorrect edge distance consideration leads to under-designed connections

Capacity in QP design:



	Load [kN]	Capacity [kN]	Utilization β_N [%]	Status
Steel Strength*	13.978	29.571	49	OK
Pullout Strength*	13.978	27.608	51	OK
Concrete Breakout Failure**	51.164	54.058	95	OK
Splitting failure**	51.164	63.667	81	OK

Actual capacity:

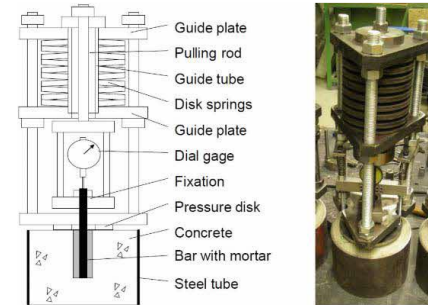


	Load [kN]	Capacity [kN]	Utilization β_N [%]	Status
Steel Strength*	12.256	25.429	49	OK
Pullout Strength*	12.256	10.457	118	not recommended
Concrete Breakout Failure**	38.723	32.296	120	not recommended
Splitting failure**	38.723	27.867	139	not recommended

Actual capacity inadequate!



- EAD assesses products for 50/100 years
- Beyond EAD limits (e.g. 120 years):
 - Technical justification required
 - Independent expert assessment
 - QP acceptance needed



Sustained Load Testing

Attn: To whom it concern

Letter of Undertaking

We agree to undertake the extend warranty of 120 years for product ABC for the project XYZ application.

Product warranty is not a technical justification

Product A: Design data for 100 years

Table C6: Design values of the bond strength $f_{bd,PIR}^{(1)}$ and $f_{bd,PIR,100y}^{(1)}$

Rebar diameter	Bond strength $f_{bd,PIR} = f_{bd,PIR,100y}$ [N/mm ²]							
	Concrete class							
	C12/15	C16/20	C20/25	C25/30	C30/37	C35/45	C40/50	C45/55
φ 8 to φ 12	1,6	2,0	2,3	2,7	3,0	3,4	3,7	4,0
φ 13 and φ 16	1,6	2,0	2,3	2,7	3,0	3,4	3,7	3,7
φ 18 to φ 32	1,6	2,0	2,3	2,7	3,0	3,4	3,4	3,4
φ 34	1,6	2,0	2,3	2,6	2,9	3,3	3,3	3,3
φ 36	1,6	1,9	2,2	2,6	2,9	3,2	3,2	3,2
φ 40	1,5	1,8	2,1	2,5	2,8	2,8	2,8	2,8

For C50/60 and φ10,
 $f_{bd,PIR} = 4.0N/mm^2$

Product A: Design data for 120 years

Table 4: 120-year design bond resistance $f_{bd,PIR}^{(1),2)}$ for diamond coring wet

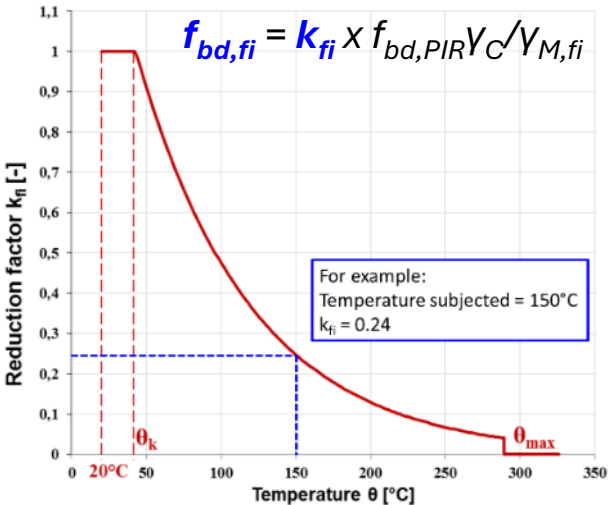
Bar diameter	Bond resistance $f_{bd,PIR}^{(1),2)}$ [N/mm ²]							
	Concrete class							
	C12/15	C16/20	C20/25	C25/30	C30/37	C35/45	C40/50	C45/55
Ø8 to Ø12	1,6	2,0	2,3	2,7	3,0	3,4	3,7	3,8
Ø14 and Ø16	1,6	2,0	2,3	2,7	3,0	3,4	3,6	3,6
Ø18 to Ø32	1,6	2,0	2,3	2,7	3,0	3,3	3,3	3,3
Ø34	1,6	2,0	2,3	2,6	2,9	3,2	3,2	3,2
Ø36	1,6	1,9	2,2	2,6	2,9	3,1	3,1	3,1
Ø40	1,5	1,8	2,1	2,5	2,7	2,7	2,7	2,7

For C50/60 and φ10,
 $f_{bd,PIR} = 3.8N/mm^2$

Extended working life can reduce bond strength and impact the design of post-installed connection



- Fire requirements (SCDF Fire Code Clause 3.3.2):
 - Fire reaction (non-combustible)
 - Fire resistance (capacity)
- Fire testing is an optional assessment in the EAD
- Verify product qualification for fire requirements



ETA of Product A: Reduction factor (k_{fi}) curve

ETA of Product A

3.2 Safety in case of fire (BWR 2)

Essential characteristic	Performance
Reaction to fire	Class A1 ✓
Resistance to fire	See Annex C 5 ✓

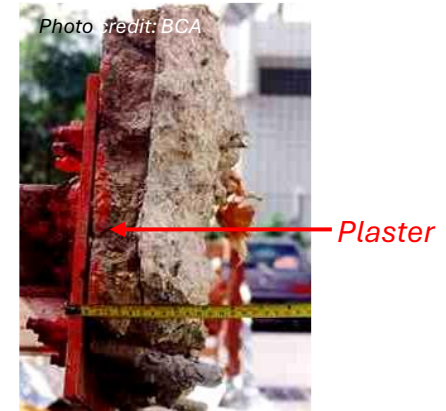
ETA of Product B

3.1.2 Safety in case of fire (BWR 2)

Essential characteristic	Performance
Reaction to fire	The post-installed rebar connection satisfies requirements for Class A1 ✓
Resistance to fire	No performance assessed X

Not all products are qualified for fire conditions

- Remove plaster and carbonated concrete
- Measure embedment depth from sound concrete
- Detailed to avoid clashing with existing reinforcement

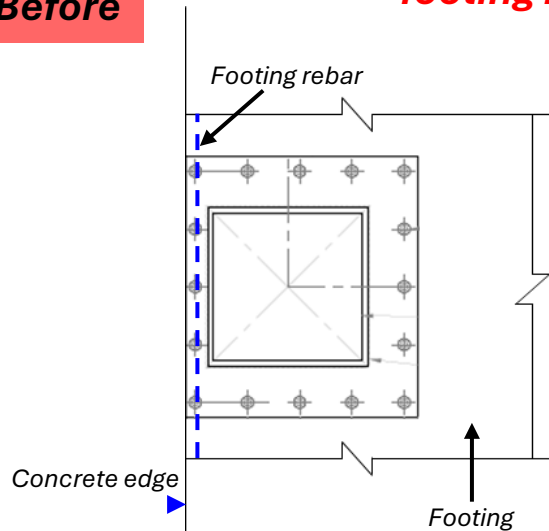


Anchors were embedded in plaster instead of concrete

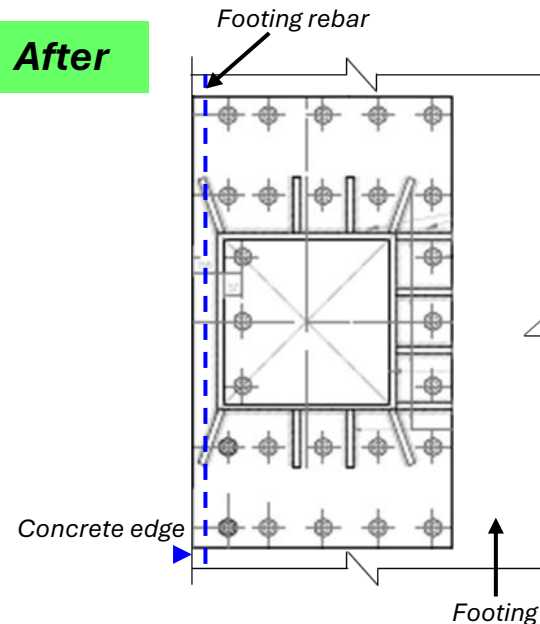
Example:

Before

Clashed with existing footing reinforcement



After



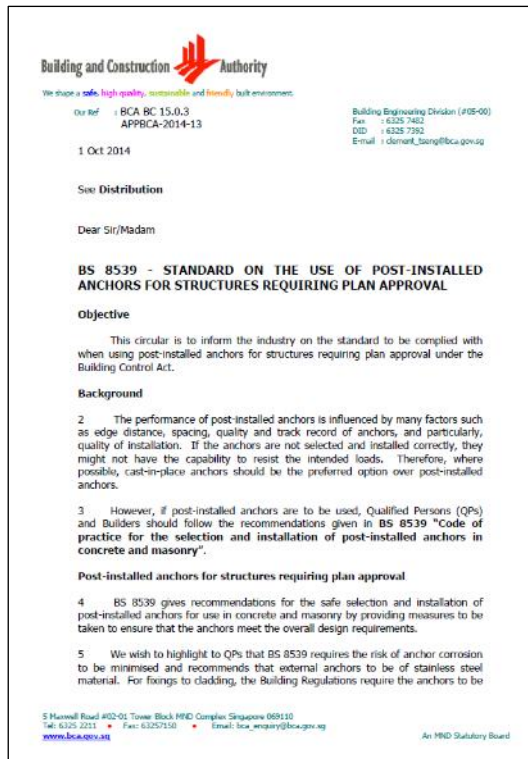
Conclusion



- Always verify that products have ETA qualification under EAD
- For tension and moment connections specifically, carefully review the design considerations, as their failures can be catastrophic
- Incorporate these essential consideration in your design and ensure proper implementation on site



1 Oct 2014 | APPBCA-2014-13
'BS 8539 – Standard on the Use of
Post-Installed Anchors for
Structures Requiring Plan Approval'



Building and Construction Authority
 We shape a *safe, high-quality, sustainable and friendly* built environment.

Our Ref: BCA BC 15.0.3
 APPBCA-2014-13

1 Oct 2014

See Distribution

Dear Sir/Madam,

BS 8539 - STANDARD ON THE USE OF POST-INSTALLED ANCHORS FOR STRUCTURES REQUIRING PLAN APPROVAL

Objective

This circular is to inform the industry on the standard to be complied with when using post-installed anchors for structures requiring plan approval under the Building Control Act.

Background

2. The performance of post-installed anchors is influenced by many factors such as edge distance, spacing, quality and track record of anchors, and particularly, quality of installation. If the anchors are not selected and installed correctly, they might not have the capability to resist the intended loads. Therefore, where possible, cast-in-place anchors should be the preferred option over post-installed anchors.

3. However, if post-installed anchors are to be used, Qualified Persons (QPs) and Builders should follow the recommendations given in BS 8539 "Code of practice for the selection and installation of post-installed anchors in concrete and masonry".

Post-installed anchors for structures requiring plan approval

4. BS 8539 gives recommendations for the safe selection and installation of post-installed anchors for use in concrete and masonry by providing measures to be taken to ensure that the anchors meet the overall design requirements.

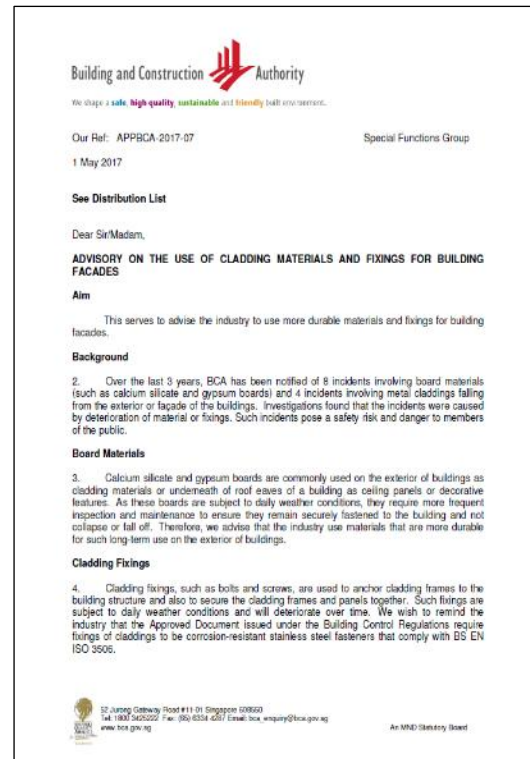
5. We wish to highlight to QPs that BS 8539 requires the risk of anchor corrosion to be minimised and recommends that external anchors to be of stainless steel material. For fixings to cladding, the Building Regulations require the anchors to be

5 Maxwell Road #02-01 Tower Block MND Complex Singapore 069110
 Tel: 6325 2211 Fax: 6325 7150 Email: bca_enquiry@bca.gov.sg
 www.bca.gov.sg

An MND Statutory Board

<https://go.gov.sg/bs8539-circular>

1 May 2017 | APPBCA-2017-07
'Advisory on the Use of Cladding
Materials and Fixings for Building
Facades'



Building and Construction Authority
 We shape a *safe, high-quality, sustainable and friendly* built environment.

Our Ref: APPBCA-2017-07
 Special Functions Group

1 May 2017

See Distribution List

Dear Sir/Madam,

ADVISORY ON THE USE OF CLADDING MATERIALS AND FIXINGS FOR BUILDING FACADES

Aim

This serves to advise the industry to use more durable materials and fixings for building facades.

Background

2. Over the last 3 years, BCA has been notified of 8 incidents involving board materials (such as calcium silicate and gypsum boards) and 4 incidents involving metal claddings falling from the exterior or facade of the buildings. Investigations found that the incidents were caused by deterioration of material or fixings. Such incidents pose a safety risk and danger to members of the public.

Board Materials

3. Calcium silicate and gypsum boards are commonly used on the exterior of buildings as cladding materials or underneath of roof eaves of a building as ceiling panels or decorative features. As these boards are subject to daily weather conditions, they require more frequent inspection and maintenance to ensure they remain securely fastened to the building and not collapse or fall off. Therefore, we advise that the industry use materials that are more durable for such long-term use on the exterior of buildings.

Cladding Fixings

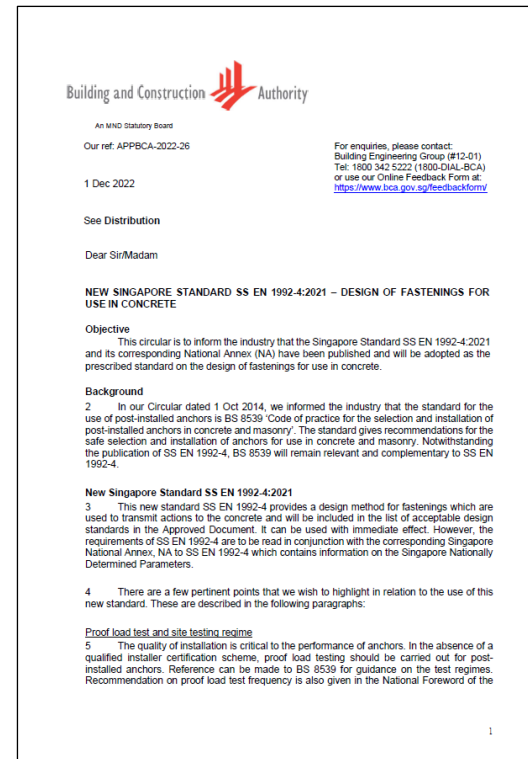
4. Cladding fixings, such as bolts and screws, are used to anchor cladding frames to the building structure and also to secure the cladding frames and panels together. Such fixings are subject to daily weather conditions and will deteriorate over time. We wish to remind the industry that the Approved Document issued under the Building Control Regulations require fixings of claddings to be corrosion-resistant stainless steel fasteners that comply with BS EN ISO 3606.

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<https://go.gov.sg/cladding-circular>

1 Dec 2022 | APPBCA-2022-26
'New Singapore Standard SS EN
1992-4:2021 – Design of Fastenings
for Use in Concrete'



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Our ref: APPBCA-2022-26

1 Dec 2022

See Distribution

Dear Sir/Madam,

NEW SINGAPORE STANDARD SS EN 1992-4:2021 – DESIGN OF FASTENINGS FOR USE IN CONCRETE

Objective

This circular is to inform the industry that the Singapore Standard SS EN 1992-4:2021 and its corresponding National Annex (NA) have been published and will be adopted as the prescribed standard on the design of fastenings for use in concrete.

Background

2. In our Circular dated 1 Oct 2014, we informed the industry that the standard for the use of post-installed anchors is BS 8539 "Code of practice for the selection and installation of post-installed anchors in concrete and masonry". The standard gives recommendations for the safe selection and installation of anchors for use in concrete and masonry. Notwithstanding the publication of SS EN 1992-4, BS 8539 will remain relevant and complementary to SS EN 1992-4.

New Singapore Standard SS EN 1992-4:2021

3. This new standard SS EN 1992-4 provides a design method for fastenings which are used to transmit actions to the concrete and will be included in the list of acceptable design standards in the Approved Document. It can be used with immediate effect. However, the requirements of SS EN 1992-4 are to be read in conjunction with the corresponding Singapore National Annex, NA to SS EN 1992-4 which contains information on the Singapore Nationally Determined Parameters.

4. There are a few pertinent points that we wish to highlight in relation to the use of this new standard. These are described in the following paragraphs:

Proof load test and site testing regime

5. The quality of installation is critical to the performance of anchors. In the absence of a qualified installer certification scheme, proof load testing should be carried out for post-installed anchors. Reference can be made to BS 8539 for guidance on the test regimes. Recommendation on proof load test frequency is also given in the National Foreword of the

For enquiries, please contact:
 Building Engineering Group (#12-01)
 Tel: 1800 342 5222 (1800-DIAL-BCA)
 or use our Online Feedback Form at:
<https://www.bca.gov.sg/feedbackform/>

<https://go.gov.sg/bca-circular-new-singapore-standard-ss-en>

3 Mar 2025 | APPBCA-2025-05
'Practical Guide for Post-Installed
Reinforcement'



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In Collaboration With:

Our ref: APPBCA-2025-05

03 March 2025

Dear Sir/Madam,

JOINT BCA/ACES CIRCULAR 2025
PRACTICAL GUIDE FOR POST-INSTALLED REINFORCEMENT

Objective

This circular is to inform the industry of the publication of the "Practical Guide for Post-Installed Reinforcement" (the "Guide"), which was jointly developed by the Association of Consulting Engineers, Singapore ("ACES") and Building and Construction Authority ("BCA") to provide guidance for the use of post-installed reinforcement (PIR).

Background

2. The PIR system is a specialised fastening technology that entails drilling holes into cured concrete of an existing structure to bond newly inserted reinforcement bars (rebars) with a qualified adhesive, replicating the behaviour of cast-in rebars. PIR is commonly used in A&A works and is widely adopted within the construction industry. However, design guidance in structural design codes, such as SS EN 1992-1-1¹, is limited and is also not covered in SS EN 1992-4².

Practical Guide for Post-Installed Reinforcement

3. The Guide covers the fundamental aspects of PIR qualification, installation, quality control, and design. It also includes detailed design steps for PIR using the design anchorage length method, designed in accordance with SS EN 1992-1-1, and the state-of-the-art design resistance method, as detailed in the EOTA Technical Report TR 069³, along with practical design examples.

¹ Eurocode 2: Design of concrete structures – Part 1-1: General rules and rules for buildings.
² Eurocode 2: Design of concrete structures – Part 4: Design of fastenings for use in concrete.
³ Design method for anchorage of post-installed reinforcing bars (rebars) with improved bond-slip behaviour as compared to EN 1992-1-1.

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BuildSG

<https://go.gov.sg/pir-circular>



The guide was **well received** and **appreciated** by the practitioners.

PRACTICAL GUIDE FOR POST-INSTALLED REINFORCEMENT



Published by
 In collaboration with
Building and Construction Authority

<https://go.gov.sg/pir-guide>

Developed **TOGETHER** with:

- **BCA**
- **ACES**
- **Prof Tan Kiang Hwee**
- **Mr. Terrence Teo**

“Great effort by ACES and BCA in publishing the Practical Guide for Post-Installed Reinforcements (PIR) to raise awareness and provide clear guidance on this important subject. This Design Guide highlights the key considerations for PIR across design, installation, and QA/QC. It will undoubtedly support our engineers in enhancing industry standards and strengthening our commitment to a safe and resilient Built Environment.”

Lin Wenjun, Vincent

Managing Director

VEngineers Consultancy Pte Ltd



“The PIR guide initiated by BCA is an **invaluable resource** for providing clear guidelines and best practices for designers and contractors. The detail guidance clarifies the ambiguity of the application of PIR and enabled us enhance our design processes and compliance with regulatory requirements. We highly recommend the PIR Guidebook be adopted widely to elevate BE standards and stay up-to-date with industry best practices.”

Tan Yew Chai

Director

DP Engineers Pte Ltd



“This publication is a **timely and invaluable resource** for professionals in the built environment, especially those involved in structural retrofitting and A&A works. The guide provides a comprehensive and well-structured overview of PIR systems, covering everything from qualification and installation to quality control and design methodologies. As a practitioner, I find the clarity and practicality of this guide helpful. It not only enhances technical knowledge but also promotes safer and more effective application of PIR in real projects.”

Ryan Nguyen

Senior Associate Director

Beca Carter Hollings &

Ferner (SE Asia) Pte Ltd



“**Practical, clear, and directly applicable** – Practical Guide for Post-Installed Reinforcement is a **go-to reference** for retrofit and strengthening work. It blends code-based design guidance with on-site best practices, making it a **valuable companion for engineers who turn concepts into safe, buildable solutions.**”

Chen Ting

Senior Engineer

AECOM Singapore Pte Ltd



“This guide is a **comprehensive and practical resource** for post-installed reinforcement. It covers essential design aspects and along with installation guidelines for site and includes valuable insights on its performance under seismic and fire conditions. It is **highly useful for engineers and construction professionals!**”

Lim Mei Yi

Executive Engineer

RSP Architects Planners &

Engineers Pte Ltd



“The guide is **extremely useful** – not only in clarifying design concepts, but also in providing step-by-step guidance for installation procedures, supervision and quality control. **Your efforts in compiling such a comprehensive and practical reference are truly appreciated.**”

Jay Low

Principal Engineer

Binnies Singapore Pte Ltd



“A **comprehensive guide to practicing engineers** for design and supervision of post-installed reinforcement”

Kam Mun Wai

Senior Executive Director

Meinhardt Singapore Pte Ltd

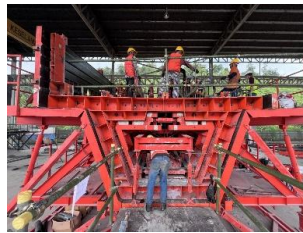
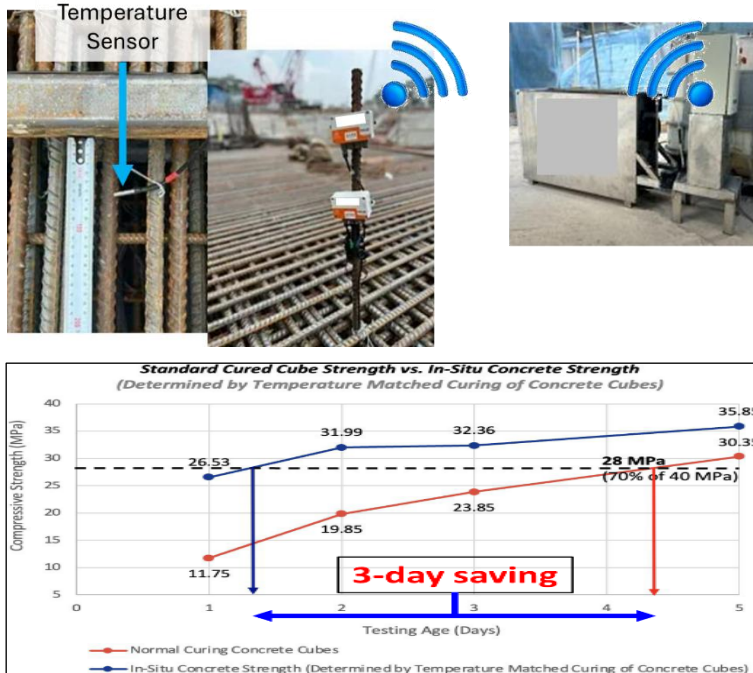


Other Industry Collaboration



Recent initiative

Temperature-Matched Curing (TMC)

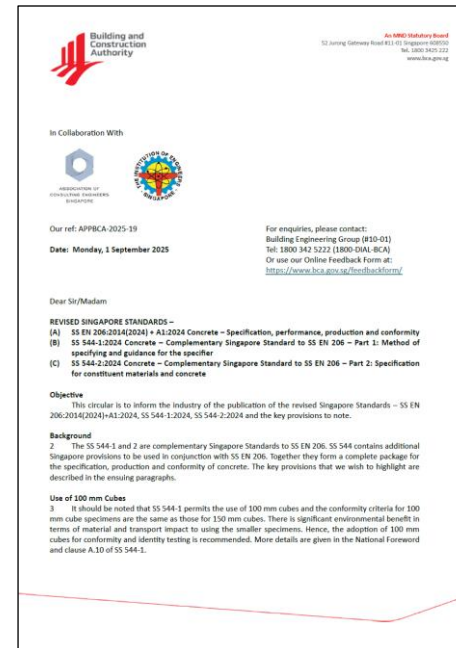


<https://go.gov.sg/tmc-circular>

The circular was developed and published **TOGETHER** with LTA and ACES to raise awareness of TMC, a method which can benefit construction productivity.

Recent initiative

Revised Singapore Standards: SS EN 206, SS 544-1, SS 544-2 Concrete specification, performance, production and conformity



- Use of 100mm cubes is encouraged
- Initial testing (trial mix) based on previous tests and long-term experience is acceptable
- Guidance on digital monitoring and measurement of fresh concrete
- Guidance on carbon dioxide utilisation and granite fines

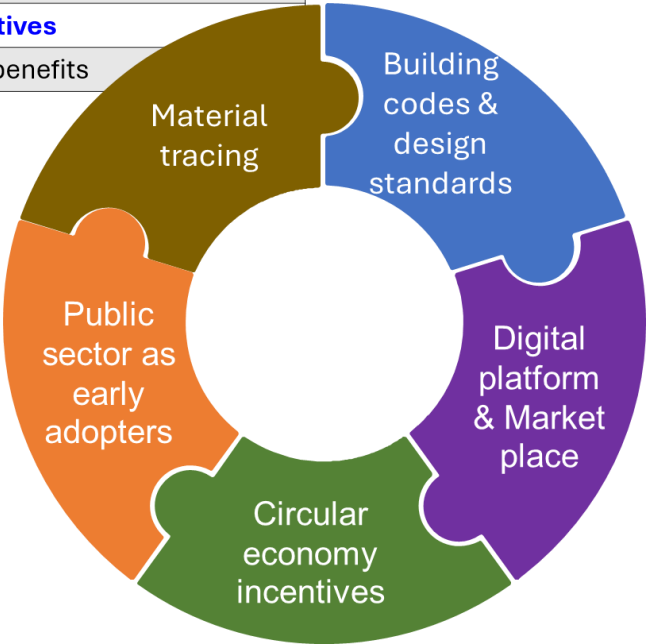
<https://www1.bca.gov.sg/docs/default-source/docs-corp-news-and-publications/circulars/appbca-2025-19-ss-en-206-ss-544.pdf>

Future initiative

Reused Steel

Facilitate steel reuse adoption for permanent structures, supporting sustainability goals

Barrier Rank	Barrier Details
1	Cost
2	Availability & Storage
3	No client demand & client perceptions
4	Quality assurance & traceability
5	Supply chain gaps & lack of supply chain integration
6	No clear financial incentive
7	Inertia in the construction sector
8	Impact on design
9	Lack of designer knowledge
10	Lack of incentives
11	Lack of defined benefits



HDB’s Project



LTA’s Project



Early adopters of reused steel TOGETHER with HDB & LTA



Er. Willie Chai
Senior Engineer

*Building and Construction Authority
Singapore*



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***Today's collaboration in
understanding, is tomorrow's
confidence in building safer
and better **TOGETHER*****

Thank you



@BCASingapore

