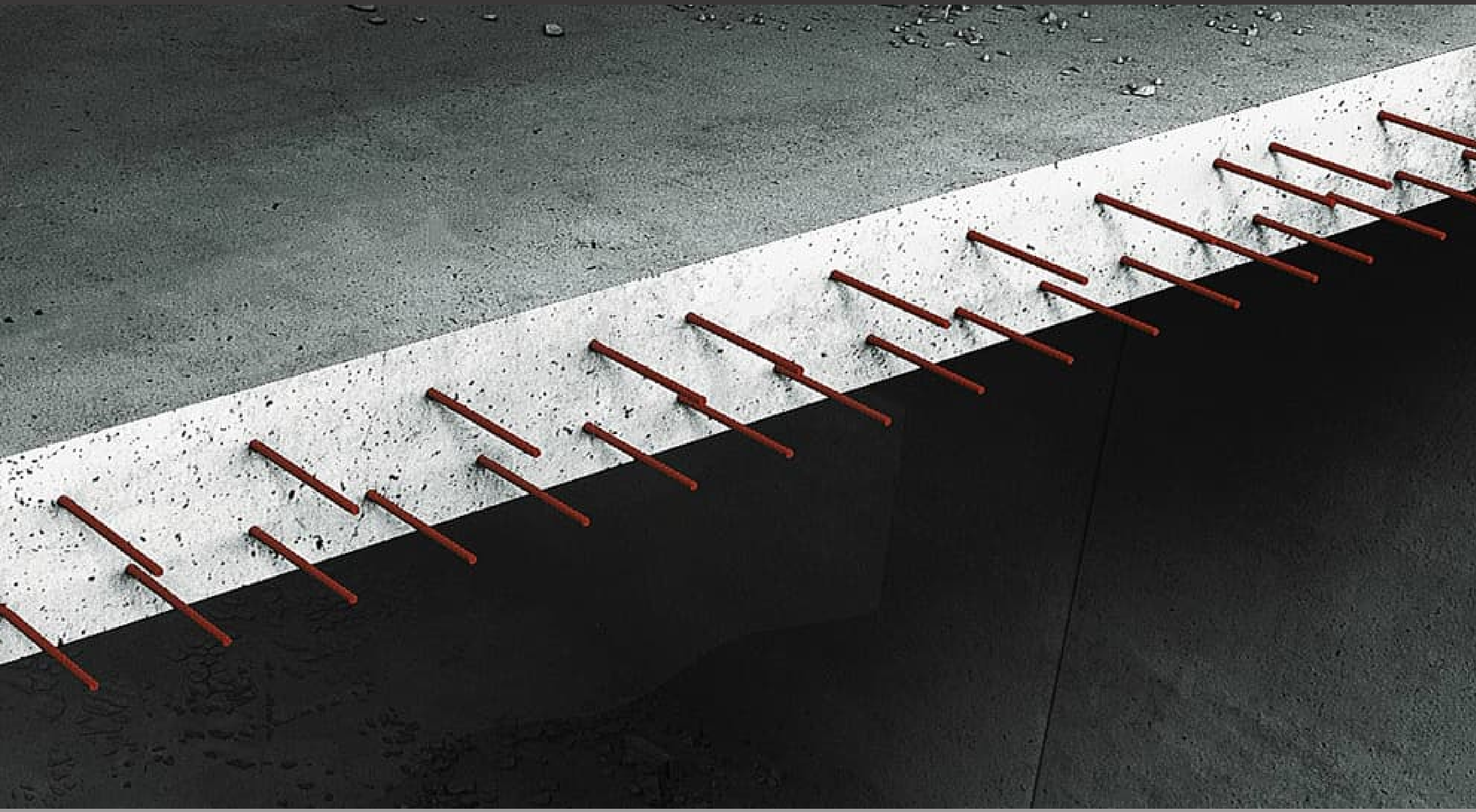
PRACTICAL GUIDE FOR POST-INSTALLED REINFORCEMENT



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Practical Guide for Post-Installed Reinforcement

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Preface

Post-installed reinforcement (PIR) is commonly used in Addition and Alteration (A&A) works and is widely adopted within the construction industry. However, specific design guidance in structural design codes, such as SS EN 1992-1-1[1], is limited. This often leads engineers to rely on product suppliers for specialised design, resulting in a limited understanding of PIR.

This Guide aims to bridge this gap by offering detailed guidance on the qualification, installation, quality control, and design of PIR, while ensuring effective and safe use of PIR applications in the industry. With a better understanding of PIR, engineers can make informed decisions and uphold the safety of structures.

The Guide covers the fundamental aspects of PIR qualification, installation, quality control, and design. It 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[2] Technical Report TR 069[3] along with practical design examples.

Presented as a technical guide and a source of recommendations, this Guide should not be treated as a specification. Care should be taken to ensure that claims of compliance are not misleading. For additional recommendations beyond those provided in this Guide, reference should be made to relevant sections of standards, technical specifications, and technical reports for PIR. It is important to note that this Guide does not claim to encompass all the necessary provisions of a contract, and users are responsible for its correct application. Compliance with the guidance in this Guide does not, in itself, confer immunity from legal obligations.

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[1] Eurocode 2: Design of concrete structures – Part 1-1: General rules and rules for buildings

[2] European Organisation for Technical Assessment

[3] Design method for anchorage of post-installed reinforcing bars (rebars) with improved bond-splitting behaviour as compared to EN 1992-1

Foreword by ACES

Formed in 1971, the Association of Consulting Engineers Singapore (ACES) is a non-profit making association representing the independent consulting engineering profession in Singapore. As part of the association's objective, ACES constantly strives to promote the engineering excellence and advancement of fellow practitioners in the built environment. Such efforts include continuous exploration of engineering techniques to address the challenges of productivity and sustainability in collaboration with industry partners as well enhancing guidance on design practices to maintain a safe built environment.

A well-designed built environment is the foundation of a resilient and progressive society. However, achieving this requires more than technical expertise, it demands a culture of continuous learning, adaptation, and adherence to best practices. In the current construction landscape, post-installed reinforcements (PIR) have become an integral solution for structural modifications, retrofitting, and various engineering applications. Given the wide adaptation of PIR and the various products available as options, it is imperative that professionals in our industry fully understand their qualification requirements, installation methodologies, quality control measures, and design considerations.

This design guide has been developed with that exact intent, to raise awareness and to provide designers with a comprehensive understanding of post-installed reinforcements in order for them to apply safely and effectively to the appropriate context. By raising awareness of fundamental principles and industry standards, ACES hope this guide will serve as a good reference for engineers, consultants, designers, and contractors, helping them make informed decisions that enhance the integrity and durability of structures.

The success of this guide is a testament to the dedication and expertise of many individuals and organizations. We would like to extend our heartfelt appreciation to the workgroup members, authors, and industry professionals whose contributions have been invaluable in bringing this publication to fruition. Special thanks also go to the officers of the Building and Construction Authority (BCA) and our esteemed partners in the construction sector for their unwavering support. Your collaboration has been instrumental in ensuring that this guide aligns with industry needs and regulatory expectations.

Er. Chuck Kho
President
Association of Consulting Engineers Singapore 2025

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- Er. Willie Chai Wei Shung & Mr Terrence Teo as Principal Contributors to the guide

- Emeritus Prof. Tan Kiang Hwee of National University of Singapore (NUS) as the Expert Peer Reviewer.

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Abbreviations

ACES	Association of Consulting Engineers Singapore
BCA	Building and Construction Authority
EAD	European Assessment Document
EMI	Electro-magnetic induction
EOTA	European Organisation for Technical Assessment
ETA	European Technical Assessment
IES	The Institution of Engineers, Singapore
IFU	Instruction for use
MPII	Manufacturer’s product installation instructions
MSDS	Material safety data sheets
PIR	Post-installed reinforcement
PPE	Personal protective equipment
PRT	Pulse radar technology
QP	Qualified person
RC	Reinforced concrete
Rebar	Reinforcement bar
SAC	Singapore Accreditation Council
SAC-SINGLAS	Singapore Laboratory Accreditation Scheme
STM	Strut and tie models
TR	Technical report

List of Symbols

For the purposes of this Guide, the following symbols apply.

A_c	Cross-sectional area of concrete, in mm^2
$A_{c,N}$	Actual projected area of the group of tensioned rebars, in mm^2
$A^{\circ}_{c,N}$	Reference projected area for concrete cone failure, in mm^2
A_k	A product-dependent factor for improved bond-splitting resistance
A_s	Cross-sectional area of rebar, in mm^2
$A_{s,min}$	Minimum cross-sectional area of the rebar, in mm^2
$A_{s,prov}$	Cross-sectional area of the rebar provided, in mm^2
$A_{s,rqd}$	Cross-sectional area of the rebar required, in mm^2
$A_{s,vmin}$	Minimum cross-sectional area of the vertical rebar, in mm^2
A_{st}	Cross-sectional area of a transverse rebar, in mm^2
F_{Ed}	Axial force in rebars, in kN
K_{tr}	Normalized ratio to consider the amount of transverse reinforcement crossing a potential splitting surface
M_{Ed}	Design bending moment, in kNm
N_{Ed}	Design axial force, in kN
$N_{Rd,c}$	Design concrete cone break-out resistance, in kN
$N_{Rd,sp}$	Design bond-splitting resistance, in kN
$N_{Rd,y}$	Design steel yielding resistance, in kN
V_{Ed}	Design shear force, in kN
b	Width of the concrete section, in mm

c	Smallest edge distance measured from the centre of the rebar, in mm
c_1 *and* c_2	Thickness of side cover in orthogonal directions 1 and 2, in mm
$c_{cr,N}$	A product-dependent factor for improved bond-splitting resistance
c_d	Design concrete cover or minimum concrete cover for improved bond-splitting resistance, in mm
c_{min}	Minimum concrete cover, in mm
c_{max}	maximum concrete cover, in mm
c_x and c_y	Thickness of side cover in orthogonal direction x and y, in mm
d	Effective depth of the beam or slab, in mm
d_0	Nominal drill hole diameter
e_N	Eccentricity of the resultant tension force with reference to the centre of gravity of tensioned rebars, in mm
f_{bd}	Design bond stress under static loading, in N/mm^2
$f_{bd,fi}$	Design bond stress under fire exposure, in N/mm^2
$f_{bd,PIR}$	Design bond stress of PIR system under static loading, in N/mm^2
$f_{bd,PIR,seis}$	Design bond stress of PIR system under seismic loading, in N/mm^2
f_{ck}	Characteristic cylinder compressive strength of concrete, in N/mm^2
f_{cm}	Mean cylinder compressive strength of concrete, in N/mm^2
$f_{ctk,0.05}$	Characteristic tensile strength of concrete at 5% fractile, in N/mm^2
f_{ctm}	Mean tensile strength of concrete, in N/mm^2
f_{yd}	Design yield stress of rebar, in N/mm^2
f_{yk}	Characteristic yield stress of rebar, in N/mm^2
g_k	Permanent action, in kN/m^2
h	Depth of the concrete section, in mm
k_1	A product-dependent factor for improved bond-splitting resistance
k_b	Reduction factor in Section 2.2.2 of EAD 330087
$k_{b,seis}$	Reduction factor under seismic load
k_{fi}	Reduction factor under fire exposure
k_m	Factor for the effectiveness of transverse reinforcement
l	Span length, in m
l_b	Embedment length or anchorage length, in mm
$lb1$	A product-dependent factor for improved bond-splitting resistance
l_{bd}	Design anchorage length, in mm
$l_{b,min}$	Minimum anchorage length, in mm
$l_{b,rqd}$	Basic anchorage length, in mm
l_o	Design lap length, in mm
$l_{o,min}$	Minimum lap length, in mm
n_b	Number of anchored or lapped bars in a potential splitting surface
n_t	Number of confining stirrup legs crossing a potential splitting surface
p_{tr}	Transverse pressure perpendicular to the longitudinal axis of PIR, in N/mm^2
q_k	Imposed load, in kN/m^2
s_1 and s_2	Distance between rebars in orthogonal directions 1 and 2, in mm
s_b	Spacing between confining stirrups, in mm
s_{crN}	A product-dependent factor for concrete cone break-out resistance
$sp1$ to $sp4$	A product-dependent factor for improved bond-splitting resistance
t	Wall thickness, in mm
z	Lever arm of section, in mm

α_2	Coefficient for the effect of minimum concrete cover to consider splitting failure
α_3	Coefficient to account for confinement effects by transverse reinforcement
α_5	Coefficient to account for the effect of the transverse pressure
α_6	Coefficient of the percentage of lapped bars relative to the total cross-section area of bars
α_{lb}	Amplification factor for minimum anchorage length
α_{sus}	Ratio of sustained actions to total actions considered at the ultimate limit state
γ_c	Material safety factor for concrete
γ_{inst}	Installation safety factor
γ_{Mc}	Material safety factor for concrete cone resistance
$\gamma_{M,fi}$	Material safety factor for concrete under fire exposure
γ_{Ms}	Material safety factor for steel under EOTA TR 069
γ_{Msp}	Material partial safety factor for improved bond-splitting resistance
γ_s	Material safety factor for steel
η_1	Coefficient for bond condition
Ω_{cr}	Reduction factor if a cracked concrete condition is assumed in the improved bond-splitting resistance calculation
$\Omega_{p,tr}$	Multiplication factor due to transverse pressure
ϕ	Diameter of rebar, in mm
σ_{sd}	Design stress in the rebar associated with the considered design action, in N/mm^2
$\psi_{ec,N}$	Factor to cater for the eccentricity between the point of application of tension force and the centre of gravity of group of rebars
$\psi_{M,N}$	Factor to consider the effect of compression stress resulting from moment-resisting actions of the concrete cone capacity
$\psi_{re,N}$	Shell spalling reduction factor for closely spaced reinforcement with an anchorage length of less than 100 millimetres
$\psi_{s,N}$	Factor to account for the disturbance effect of distribution stress due to the edge of concrete members
ψ_{sus}	Factor to account for the effects of sustained loads
ψ°_{sus}	Factor taken from product ETA or assumed at 0.6
$\tau_{Rk,sp}$	Characteristic bond resistance in cracked concrete, in N/mm^2
$\tau_{Rk,ucr}$	Characteristic bond resistance in uncracked concrete, in N/mm^2

Chapter 1

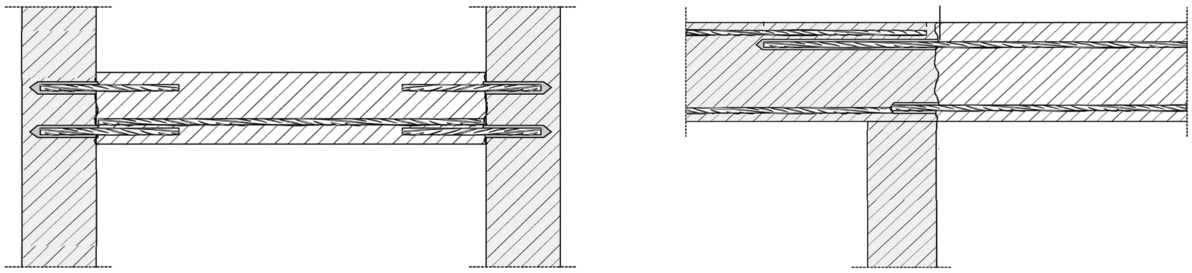
Introduction

1.1. POST-INSTALLED REINFORCEMENT

The post-installed reinforcement (PIR) system is a specialised fastening technology that entails drilling holes into cured concrete of an existing structure to bond newly inserted reinforcement bar (rebar) with a qualified adhesive, replicating the behaviour of cast-in rebar. The protruded rebars typically serve as starter bars to facilitate lap splicing with the reinforcement in new concrete structures or a lapped joint with the reinforcement already present in the existing member. It is important to emphasize that the PIR system differs from post-installed anchors (referred to as post-installed fasteners), as PIR is utilised for concrete-to-concrete connections, while post-installed fasteners are employed for steel-to-concrete connections.

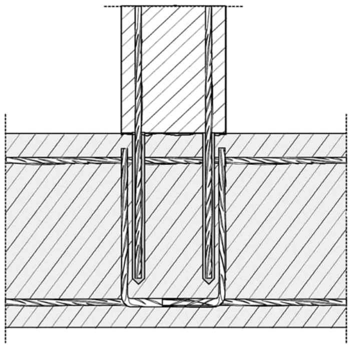
1.2. APPLICATIONS OF POST-INSTALLED REINFORCEMENT

The utilisation of PIR is extensive in construction for addition and alteration works, providing support for newly cast concrete members, and addressing issues related to misplaced reinforcement. PIR is adaptable and can be employed in nearly any concrete location, including horizontal, vertical, and overhead applications. It presents a rapid and convenient solution for introducing new reinforcement in an existing reinforced concrete (RC) structural system, proving to be an effective method for enhancing and upgrading existing structures. PIR can be utilised in various construction scenarios, such as constructing a new RC slab or beam onto an existing RC wall or column, extending a RC slab or beam, and integrating an RC column into the foundation, as illustrated in Figure 1.



(a) New RC slab or beam onto an existing RC wall or column

(b) Extending a RC slab or beam

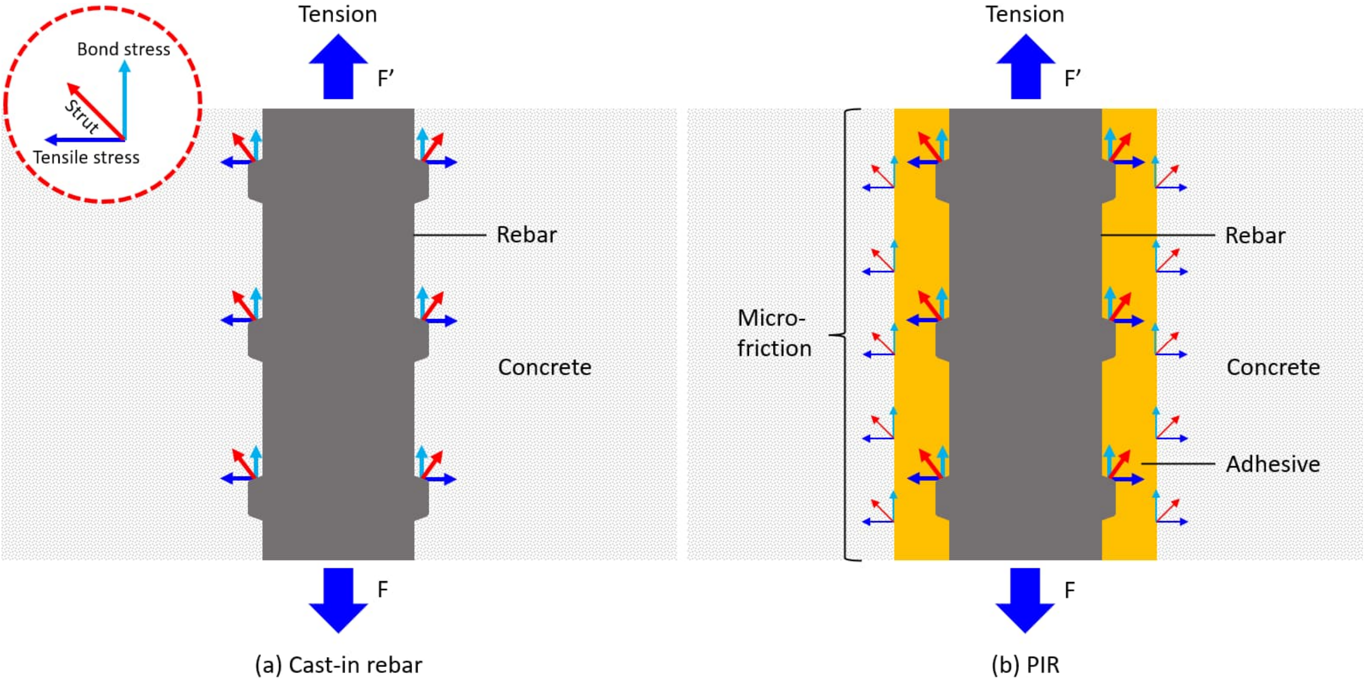


(c) RC column into the foundation

Figure 1. Typical application examples of PIR, adopted from European Assessment Document EAD 330087

1.3. MECHANISM OF LOAD TRANSFER IN POST-INSTALLED REINFORCEMENT

Rebars must possess adequate bond strength to effectively interact with the surrounding concrete. In the design process, a uniform bond model is typically assumed, ensuring a consistent average bond stress distribution along the embedded length of both cast-in rebars and PIR. In the case of cast-in rebars, the primary load transfer mechanism relies on the mechanical interlock provided by the ribs at the rebar-concrete interface, resulting in compressive struts inclined to the rebar axis within the concrete. Conversely, for PIR, the load transfer occurs in two steps: first, the surrounding adhesive resists the load from the rebar, similar to the mechanism of cast-in rebars directly on concrete; second, this load is then transferred from the adhesive to the surrounding concrete through micro-friction and adhesion. The interaction among the rebar, adhesive, and concrete strongly depends on the product and therefore necessitates an assessment procedure. These load transfer mechanisms are illustrated schematically in Figure 2.



(a) Cast-in rebar

(b) PIR

Figure 2. Mechanism of load transfer in cast-in rebar and PIR

1.4. ESSENTIAL MATERIALS FOR POST-INSTALLED REINFORCEMENT

1.4.1. Adhesive

The proper functioning of the PIR system is heavily dependent on the adhesive used. It is important to note that certain adhesives for post-installed fastening systems may not be suitable for PIR. Only adhesives approved for PIR, as covered by European Assessment Document EAD 330087 and issued with a European Technical Assessment (ETA), should be used. Several factors influence adhesive selection, including loading direction, working life, environmental considerations (such as temperature range), fire exposure, anchorage length, rebar diameter, drilling method, and on-site conditions. The ETA of the adhesive specifies these factors, and readers should refer to the respective ETA for further guidance and selection. It is worth noting that PIR adhesive is often referred to as 'mortar' or 'chemical'. This guide will consistently use the term 'adhesive' for consistency and clarity.

1.4.2. Concrete

The PIR system is designed for use in non-carbonated (due to weathering), well-compacted concrete ranging from concrete strength class C12/15 to C50/60, as outlined in EAD 330087. In the case of higher concrete strength class (exceeding f_{ck} = 50MPa), the bond strength of PIR is capped at the limit for C50/60. Additionally, the minimum thickness of the existing concrete members where the rebar will be installed must be equal to or greater than the sum of the anchorage length of the PIR and the concrete cover, as illustrated in Figure 3.

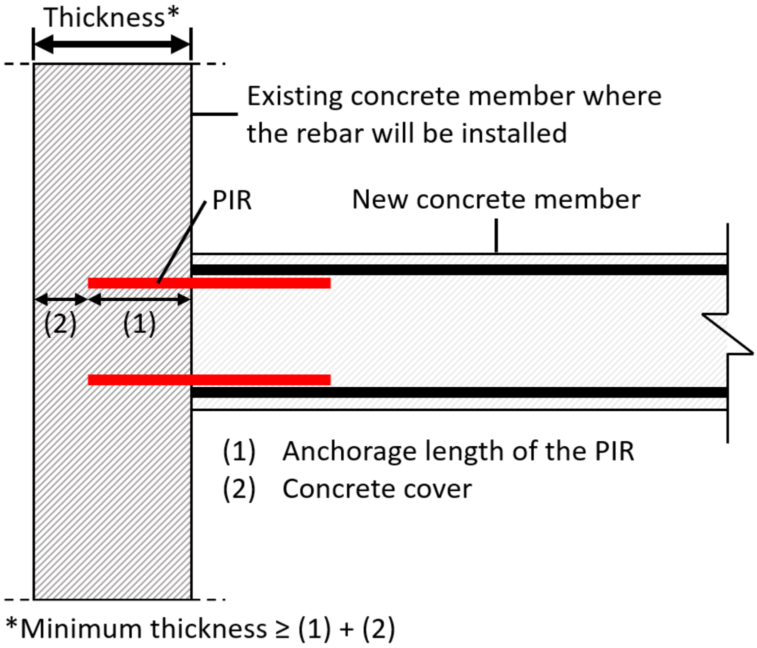


Figure 3. Minimum thickness requirements for existing concrete members

1.4.3. Reinforcement

The steel reinforcement must adhere to the standards SS EN 1992-1-1 and SS 560. It is important to highlight that 250MPa plain round bars are not suitable for use in PIR systems.

1.5. RELEVANT STANDARDS, TECHNICAL SPECIFICATIONS, AND TECHNICAL REPORTS

Several standards, technical specifications, and technical reports are relevant to PIR, as summarized in Table 1. The details of these relevant documents will be further elaborated in Chapters 2 and 5.

Table 1. List of relevant standards, technical specifications and technical reports on PIR*

Document	Document title	Roles and functions
SS EN 1992-1-1 and NA to SS EN 1992-1-1	Design of concrete structures – Part 1-1 General rules and rules for buildings and the corresponding National Annex	Design standard
SS EN 1992-1-2 and NA to SS EN 1992-1-2	Design of concrete structures – Part 1-2 General rules – Structural fire design and the corresponding National Annex	Design standard
SS EN 1998-1 and NA to SS EN 1998-1	Design of structures for earthquake resistance – Part 1: General rules, seismic actions and rules for buildings and the corresponding National Annex	Design standard
EOTA TR 069	Design method for anchorage of post-installed reinforcing bars (rebars) with improved bond-splitting behaviour as compared to EN 1992-1-1	Design guide
EAD 330087-01-0601 This Guide uses concise names, such as EAD 330087.	Systems for post-installed rebar connections with mortar	Technical specifications of PIR connections with mortar under static, seismic loading, and fire exposure
EAD 332402-00-0601 This Guide uses concise names, such as EAD 332402.	Post-installed reinforcing bar (rebar) connections with improved bond-splitting behaviour under static loading and under seismic action	Technical specifications of PIR with improved bond-splitting behaviour under static loading and seismic action for rigid connection

*Reference should be made to the latest versions of the applicable standards, technical specifications and technical reports.

Chapter 2

Qualification of Post-Installed Reinforcement

2.1. BASIC PRINCIPLES

The effectiveness of the PIR system depends on various factors, including the adhesive type, drilling and installation methods, and the specified length and diameter of the holes. Adhering to appropriate technical specifications is essential to ensure that the behaviour of the PIR system aligns with that of a monolithic cast-in rebar.

In Europe, the European Organisation for Technical Assessment (EOTA) has issued technical specifications and design guides for PIR. The use of PIR is limited to products that have undergone assessment against the EAD 330087. This document covers static and seismic loading conditions, as well as fire exposure for a working life of 50 and 100 years. EAD 330087 allows for coverage of the complete range of working life categories outlined in SS EN 1990, and a product assessed in accordance with this EAD is granted an ETA. The ETA includes technical data, performance characteristics, design parameters based on design standards or guides, and the appropriate installation method.

The primary objective of the technical specifications EAD 330087 is to ensure that the performance of PIR systems is comparable to that of cast-in rebars for failure modes under static and seismic actions. The basic tension test procedure assesses the average bond strength of a PIR system under various conditions, including dry or wet environments, temperature, direction, depth, corrosion, and alkaline or sulphurous environments. Additionally, it provides testing provisions to evaluate the product's performance under fire exposure. It is important to note that PIR connections in structures loaded by fatigue are beyond the scope of this EAD. PIR systems assessed in accordance with EAD 330087 can be used for anchorages and lap splices designed following the provisions of SS EN 1992-1-1 and SS EN 1998-1.

EAD 332402 represents a state-of-the-art method introduced to assess the product-dependent performance of PIR systems, often surpassing that of cast-in rebars. However, products assessed in accordance with EAD 332402 cannot be designed using the Eurocodes. Instead, EOTA has introduced technical reports (TR), namely EOTA TR 069. Products with an ETA in accordance with EAD 332402 can be designed for anchorages in moment-resisting connections without the need for existing rebar for lapping, following the provisions of EOTA TR 069. Table 2 provides an overview of the PIR technical specifications with the corresponding design documents.

Table 2. PIR technical specifications with the corresponding design documents

Technical specification	Corresponding design document
EAD 330087	SS EN 1992-1-1 and NA to SS EN 1992-1-1 SS EN 1998-1 and NA to SS EN 1998-1
EAD 330087 **and** EAD 332402	EOTA TR 069

2.2. INTRODUCTION TO EAD 330087 and EAD 332402

EAD 330087 and EAD 332402 cover essential tests, test conditions, evaluation methods, and assessment criteria required for preparing an ETA for PIR systems. Table 3 outlines the pertinent points for EAD 330087 and EAD 332402.

Table 3. Pertinent points for EAD 330087 and EAD 332402, modified from Looi et al., 2023

Test assessment	**EAD 330087**	**EAD 332402**
Adhesive pull-out strength	The average bond strength of the tested PIR system must meet the requirements specified in EAD 330087. If the PIR system demonstrates a lower average bond strength but still satisfies the minimum bond strength of 7.1MPa, the bond strength is reduced using the reduction factor $k_b \leq 1.0$ as presented in the respective ETA. This factor is used to calculate the design bond strength of the PIR system, $f_{bd,PIR} = k_b \text{ x } f_{bd}$.	The beam-end test (unconfined) is employed to ascertain the local bond-splitting for PIR in uncracked concrete, whereas the global bond-splitting is derived based on confined splitting specimens. The setup for both tests is provided in EAD 332402.
Adhesive splitting strength	As specified in EAD, this is equivalent to the splitting strength of cast-in rebars.	
Sensitivity to cracked concrete	This check on bond strength and displacement for cracked concrete is primarily conducted to prevent an increase in the minimum anchorage length. If a PIR system fails to meet this requirement, the minimum anchorage length ($l_{b,min}$) must be increased by 50% to reduce the probability of the PIR being affected by a longitudinal crack along its entire length. This adjustment is expressed in the ETA by the amplification factor $\alpha_{lb} > 1.0$. This increase is not required if tests demonstrate that the bond strength of PIR and cast-in rebar in cracked concrete is similar (therefore, $\alpha_{lb} = 1.0$).	
Minimum edge distance and concrete cover	Different drilling methods transfer varying amounts of destructive energy into the concrete to produce the borehole. To ensure the performance of the PIR and to avoid damaging the concrete during borehole drilling, EAD 330087 stipulates minimum values for the concrete cover (c_{min}) and clear spacing between two PIR. These requirements are specified in the respective product ETA document as well. These factors are reduced when drilling aid devices, such as drill stands, are used to ensure that the borehole is oriented perpendicular to the surface of the concrete member.	

2.3. WORKING LIFE

EAD 330087 certifies adhesives for a working life of 50 and 100 years. Sustained load tests are conducted for a minimum period of 3 months to assess the creep behaviour. The resulting displacements from these tests are extrapolated to align with a working life of 50 and 100 years and must not exceed specified limits to ensure equivalence with the behaviour of cast-in rebar. To validate a 50- and 100-years working life of the connection, the durability of the adhesive and the corrosion protection for the PIR are also evaluated under EAD 330087.

For PIR systems requiring a working life beyond the specified limit in EAD 330087, guidance from the product manufacturer, supported by an independent PIR expert assessment and substantiated with technical justifications, should be sought regarding the product's working life. Additionally, where building works are involved, the approval of the qualified person (QP) who has statutory responsibility for the structural safety of the building works under the building regulations, is necessary.

2.4. RESISTANCE TO SEISMIC ACTION OF THE POST-INSTALLED REINFORCEMENT

The bond capacity of PIR is anticipated to deteriorate under cyclic loading, such as seismic action, leading to the need for assessing lower bond strengths in PIR systems to account for the adhesive's sensitivity to alternating cyclic loading (Borosnyoi et al., 2021).

EAD 330087 outlines assessment methods for PIR subjected to seismic loads, with the aim of ensuring that the bond strength degradation of PIRs, as the number of cycles increases, is not worse than that of a cast-in rebar.

The relevant product ETA document provides seismic reduction factors ($k_{b,seis}$) for calculating the design bond strength under seismic conditions ($f_{bd,PIR,seis}$), with the intention of replacing the bond strength under static loading. It is essential to qualify the PIR system under static loading as a prerequisite before proceeding to seismic assessment.

2.5. RESISTANCE TO FIRE OF THE POST-INSTALLED REINFORCEMENT

The fire safety of PIR systems is crucial in practical applications, as the adhesive used for bonding is highly sensitive to temperature. EAD 330087 outlines the required tests for evaluating the PIR system's performance under fire exposure, involving subjecting the PIR to a series of tests using a constant load method and gradually increasing the temperature. The resulting curve from the test is used to determine the reduction factor, k_{fi}, plotted over the temperature, and this data is reported in the respective product ETA document (refer to the sample curve in Figure 4).

The temperature is contingent on the specific application, such as the geometry of the concrete structure in which PIR is installed. Through thermal simulations, for example using the finite element method, the temperature profile over time for specific model structures can be determined by subjecting the structure surface to the ISO 834 fire curve. The temperature profile for RC elements with general geometric configurations can also be found in Annex A of SS EN 1992-1-2. This profile provides information based on the temperature distribution in rebar due to geometry and for fire durations corresponding to R30 to R240.

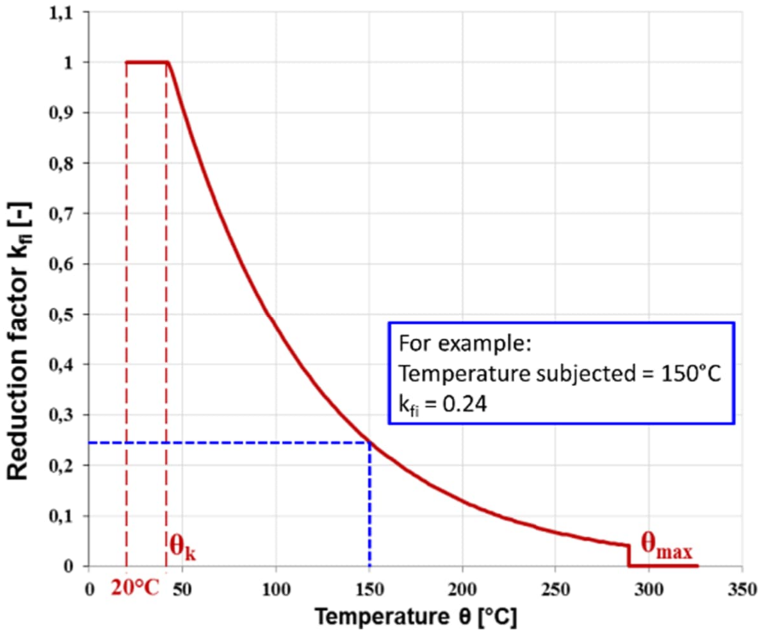


Figure 4. Sample of curve representing the reduction factor over the temperature, adopted from EAD 330087

The temperature profile, in conjunction with the reduction factor curve, enables the calculation of the reduced bond strength for specific fire durations. Figure 5 illustrates the steps to obtain the reduced bond strength for PIR ($f_{bd,fi}$). It is imperative to note that meeting the minimum cover stipulated in SS EN 1992-1-1 alone is insufficient to address the fire concerns for PIR. PIR must undergo assessment based on the steps illustrated in Figure 5 for fire resistance. Additionally, the fire design of PIRs shall also follow the design rules as stipulated in SS EN 1992-1-2. The material safety factor ($\gamma_{M,fi}$) shall be taken as 1.0 as recommended in NA to SS EN 1992-1-2.

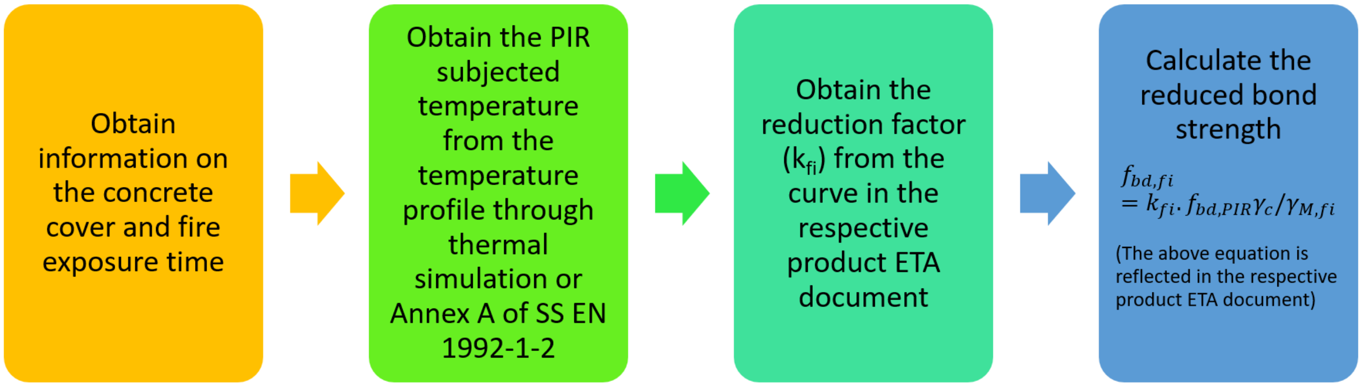
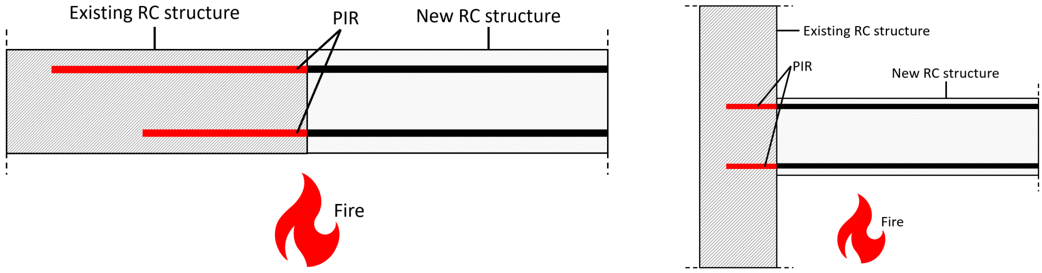


Figure 5. Steps to obtain the reduced bond strength for PIR due to fire exposure

Two common types of PIR connections are identified in relation to fire exposure: parallel and anchorage connections, as illustrated in Figure 6. Each type exhibits specific temperature gradients along the rebar. In parallel connections, the temperature gradient along the rebar remains constant due to consistent concrete cover against the fire. Conversely, the temperature gradient along the rebar for anchorage connections is not constant due to varying fire exposure. As a result, the heat transfer experienced for anchorage connections is expected to be smaller, leading to lower temperatures compared to parallel connections (Mahrenholtz et al., 2020).



(a) Parallel connection (overlapping joint) (b) Anchorage connection (end anchoring)

Figure 6. Types of PIR connections in relation to fire exposure

2.6. QUALIFICATIONS FOR POST-INSTALLED REINFORCEMENT IN SINGAPORE

Singapore has adopted the Eurocodes, and the qualification of the PIR system as per EAD is more compatible with the Eurocodes. Therefore, the PIR system product used in Singapore should hold an ETA to EAD 330087 and/or EAD 332402.

Chapter 3

Installation Guidelines and Recommendations for Post-Installed Reinforcement

3.1. INTRODUCTION

The correct installation procedure for PIR systems in construction is crucial to ensure the following:

(a) **Safety**
Proper installation is crucial for ensuring the safety of the structure and its occupants. Incorrectly installed PIR may fail prematurely, resulting in structural failure or damage, leading to potential life and economic losses.

(b) **Performance**
The performance of the PIR system significantly depends on the quality of installation. Incorrect installation may lead to reduced load performance and potential system failure.

(c) **Quality**
Proper installation is essential to ensure the quality of the finished construction. Incorrect installation may result in non-compliance with required standards, leading to costly repairs or even complete re-installation or re-build.

This chapter provides guidance and recommendation for the proper and safe installation of qualified PIR systems.

3.2. INSTALLER AND SITE SUPERVISOR COMPETENCY

PIR work is recommended to be carried out by competent installers in accordance with construction documents, manufacturer’s product installation instructions (MPII), instructions in product ETA, and/or the system’s instruction for use (IFU), which should be obtained from the product’s manufacturer.

The installer and site supervisors are recommended to acquire, at a minimum, the following from the product manufacturer's appointed representative:

(a) Training – The installer should receive practical hands-on training on the correct procedures and tools for proper PIR installation. The training should be specific to the specified PIR system, as installation requirements vary between different PIR systems and design requirements.

(b) Knowledge – The installer and site supervisor shall obtain knowledge of PIR function and be aware of the consequences of non-compliance with construction documents, MPII, product ETA and/or IFU, and material safety data sheets (MSDS).

(c) Experience – If the installer has limited experience, closer supervision should be provided.

3.3. PIR INSTALLATION PROCESS

Below is the general sequential procedure for PIR installation (refer to the QP design requirements, the MPII, and product ETA and/or IFU for details):

(a) **Detection and positioning:**
Locate existing reinforcement and other objects within the base material to determine a safe drilling location for the PIR.

(b) **Roughening of existing concrete:**
Roughen existing concrete surface at the joint interface to ensure a good connection between the old and new concrete, as well as to remove the carbonated layer if present (see Section 3.3.2).

(c) **Drilling of hole:**
Drill a hole with the required diameter and depth, as per the design, into the existing concrete.

(d) **Cleaning of hole:**
Clean the drilled hole thoroughly as per ETA.

(e) **Injection of adhesive:**
Inject the selected PIR adhesive into the drilled hole, starting from the bottom of the hole, ensuring that the hole is filled with minimal or no air voids to the volume needed for the adhesive to bond the entire length of the rebar inside the hole.

(f) **Setting of rebar:**
Insert the PIR to the required design embedment depth before the working time of the adhesive has elapsed.

(g) **Curing:**
Observe the required full curing time before casting of new concrete and application of full load.

3.3.1. Detection and Positioning

Detecting and locating reinforcement and other embedded items within existing concrete is recommended to prevent accidental damage during the hole drilling process. In the case of lap splices with PIR, this is also important to assess and determine the position of the PIR relative to the existing cast-in rebars for lapping. For non-destructive detection, the following technologies are available for consideration:

(a) Electro-magnetic induction (EMI) scanners – typically used to locate reinforcing rebars within 200-250mm of the existing concrete surface.

(b) Pulse radar technology (PRT) scanners – suitable for locating both ferrous (e.g., rebar) and non-ferrous embedded items (e.g., aluminium conduits).

(c) Scanners utilizing X-ray technology – may be necessary for areas with heavy congested rebars or where existing rebars are too deep for EMI or PRT systems to detect accurately.

Where possible, scanning results are best supplemented with as-built drawings or original design documents.

3.3.2. Removal of Carbonated Layer and Roughening of Existing Concrete Surface

In case the surface layer of existing concrete is carbonated, the carbonated layer shall be removed in the area of the PIR connection with a recommended diameter of ϕ + 60 mm prior to the installation of the new rebar (see Figure 7). The depth of concrete to be removed shall correspond to at least the minimum concrete cover, c_{min} in accordance with SS EN 1992-1-1.

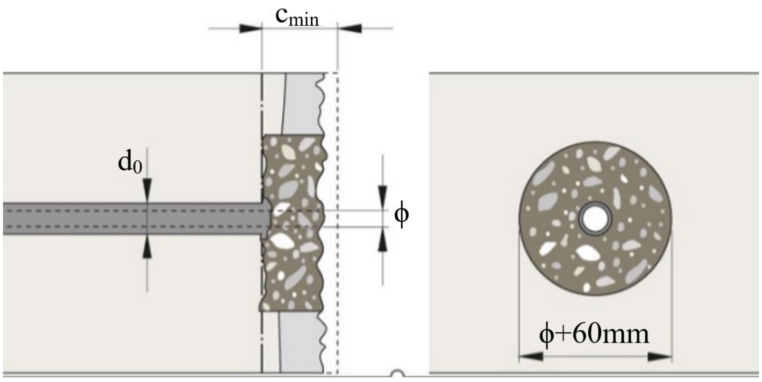


Figure 7. Removal of carbonated concrete layer (not to scale)

The surface of the existing concrete should be suitably rough for good adhesion and increase joint friction with the new concrete. To ensure the joint's ability to transfer shear where new concrete is to be applied to existing concrete, roughening should be provided to the intended use according to SS EN 1992-1-1 Clause 6.2.5(2) where the surface should be with at least 3 mm roughness at about 40 mm spacing (see Figure 8). Roughening of concrete can be accomplished by mechanical means giving an equivalent behaviour for the intended use to SS EN 1992-1-1 for the joint design.

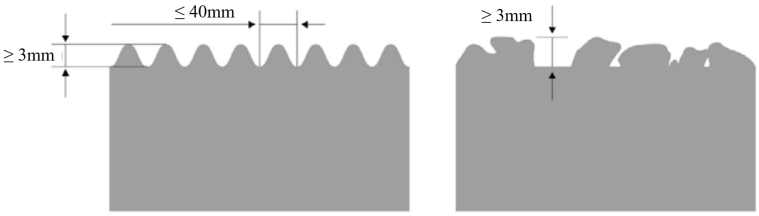


Figure 8. Rough surface guidance based on SS EN1992-1-1 Clause 6.2.5(2) (not to scale)

3.3.3. Hole Drilling

PIR typically requires drilling to deeper embedment depths to achieve the design anchorage length. Correct hole drilling and cleaning is critical for the performance and reliability of the PIR. The drilled hole should be perpendicular to existing concrete surface, unless designed otherwise, and drilling should not lead to spalling or splitting of existing concrete. Detailed instructions (e.g. equipment/accessories to be used and drill bit sizes) are available in MPII, product ETA and/or IFU.

The drilling of holes required for installing PIR are typically performed using the following methods:

(a) Hammer drills equipped with standard or cruciform carbide drill bits or hollow automatic cleaning drill bits

Hammer drilling is a commonly preferred method for most applications. Hammer drills with correct drill bits produce non-uniform, rough hole surfaces suitable for PIR adhesive bond (provided correct hole cleaning procedures are observed). Holes should be drilled in accordance with equipment and drill bits stated in MPII, product ETA and/or IFU.

Dust produced during hammer drilling affects the reliability and performance of the bond and is detrimental to environmental health and safety. The use of hollow automatic cleaning drill bits, which allow concurrent vacuum extraction of dust from inside the hole during the drilling process, can be considered. This increases productivity by reducing the need for subsequent cleaning of the hole and improves jobsite health and safety by significantly reducing dust. Refer to MPII and product ETA for qualifications and use of hollow automatic cleaning drill bits for the PIR system.

Hammer drilling becomes less practical when very deep holes are needed or when cutting through existing reinforcement is required.

Note: Drilling through existing reinforcement or other embedded objects should not be undertaken without prior approval from the relevant QP.

(b) Compressed air/percussive rock drills

Compressed air or percussive rock drills offer greater speed and efficiency compared to hammer drilling. They produce a rough drilled hole surface which is suitable for the PIR adhesive bond. However, due to large impact energy, this drilling method may cause damage to existing concrete during the drilling process. As such, this method is more suitable for conditions where larger concrete edge distances, rebar spacing or more existing concrete member thickness (more back cover) are available.

(c) Core drills or Coring

Core drilling (wet or dry) using high performance diamond tipped core bits and coring machines can produce very long and straight holes. This is the preferred method for drilling safely to deep embedment depths.

Core drilling produces a very smooth hole surface usually covered with a thin film of dust. This is deleterious to bond, hence core drilled holes must be thoroughly cleaned prior to injection of the adhesive. Specific hole cleaning procedures for core drilled holes must be carried out to achieve the requisite bond strength for the PIR design. These are given in MPII and product ETA.

Some adhesive systems are not qualified for use with diamond core drilled holes. For products qualified for diamond core drilled holes, the corresponding design bond strengths are given in the product ETA for different conditions of diamond core drilling (wet or dry) and if the cored holes are roughened with suitable roughening tool.

3.3.4. PIR Spacing and Installation with Small Cover

The PIR should be detailed according to SS EN 1992-1-1 and the product ETA requirements (including concrete cover, spacing, substrate thickness, surface roughness, etc) to prevent spalling or large cracks during drilling and to ensure the required load transmissions as per the design can be achieved.

Similar to cast-in rebars, the PIR must have adequate concrete cover to prevent rebar corrosion. It should be installed with adhesive surrounding the rebar along its entire length. Additionally, sufficient concrete edge distance must be ensured to facilitate drilling without causing splitting or spalling in the existing concrete, while also maintaining the required load transmission as per the design.

Drilling aids are recommended to ensure the perpendicular angle of the drilled holes to the concrete surface and improve drilling accuracy (see Figure 9).

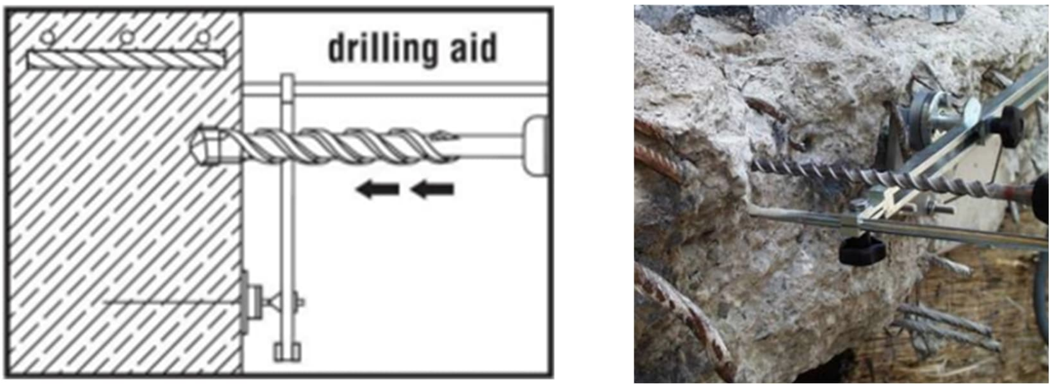


Figure 9. Example of drilling aids used close to edge of existing concrete

Detailed rules for minimum concrete cover in case of drilling with or without drilling aids are available in EAD 330087 and are specifically given in product ETA (see Table 4).

Table 4. Minimum concrete cover requirements from EAD 330087 for PIR with or without drilling aids.

Drilling Method	**Rebar diameter (mm)**	**Minimum concrete cover c_{min} (mm)**	
		Without drilling aid	**With drilling aid**
Hammer drilling or diamond drilling	$\phi < 25$	$c_{min,req} = 30 + 0.06 l_v \geq 2\phi$	$c_{min,req} = 30 + 0.02 l_v \geq 2\phi$
	$\phi \geq 25$	$c_{min,req} = 40 + 0.06 l_v \geq 2\phi$	$c_{min,req} = 40 + 0.02 l_v \geq 2\phi$
Compressed air drilling	$\phi < 25$	$c_{min,req} = 50 + 0.08 l_v$	$c_{min,req} = 50 + 0.02 l_v$
	$\phi \geq 25$	$c_{min,req} = 60 + 0.08 l_v \geq 2\phi$	$c_{min,req} = 60 + 0.02 l_v \geq 2\phi$

Note :

(a) Minimum clear spacing between two PIRs is 40mm or 4ϕ, whichever is greater
(b) l_v is the drilling/anchorage length of the PIR in concrete in mm
(c) ϕ is the diameter of the PIR in mm
(d) $c_{min,req}$ is the minimum concrete cover to prevent damage of concrete during drilling (see Figure 10)

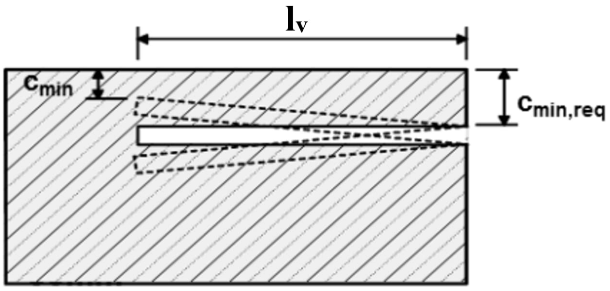


Figure 10. $c_{min,req}$ is intended to increase probability that the end of the installed PIR will remain within the minimum required concrete cover c_{min}

For practicality, clear spacing of adjacent PIRs should be maintained at a minimum of 40mm or 4ϕ, whichever is greater, as per EAD 330087. The respective product ETA should be referred to for details on the spacing requirement. Where applicable, SS EN 1992-1-1 provisions for cover and rebar spacing should be observed.

Lapped splices with PIR should be detailed according to SS EN 1992-1-1 Clause 8.7.2. The clear distance between the lapping PIR and cast-in rebar should not be greater than 4ϕ or 50mm. The spacing requirements for lapped splices with PIR are illustrated in Figure 11. If the clear distance between lapping bars exceeds 4ϕ or 50mm, then the lap length shall be increased by the difference between the clear distance and 4ϕ or 50mm, whichever is greater.

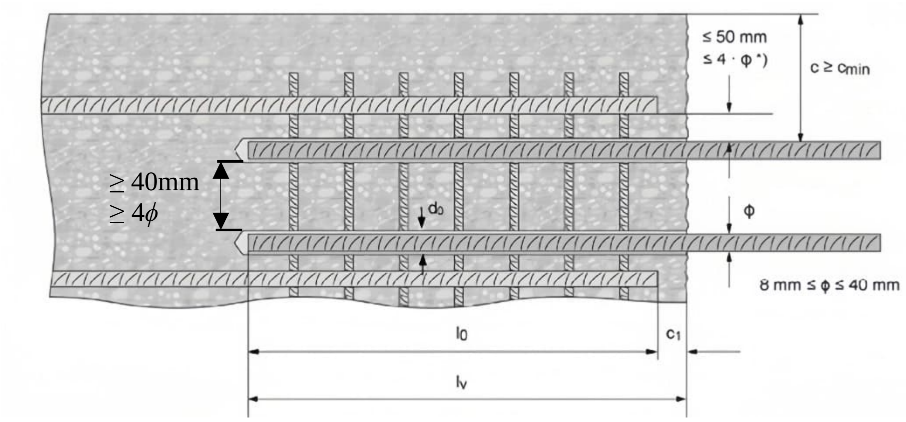


Figure 11. Spacing requirements for lapped splices with PIR

ϕ	diameter of rebar
c	concrete cover of post-installed rebar
c_1	concrete cover at end-face of existing rebar
c_{min}	minimum concrete cover according to Table 4 and to SS EN 1992-1-1
d_0	nominal drill bit diameter
l_0	lap length, according to SS EN 1992-1-1 for static loading and according to SS EN 1998-1, for seismic loading
l_v	embedment length $\geqslant l_0 + c_1$

3.3.5. Hole Cleaning

The bond between the adhesive and concrete is significantly influenced by the condition of the drilled hole wall at the time of adhesive injection. It is crucial to clean the borehole to ensure the removal of dust or debris, as these may otherwise affect the bond of the adhesive to the hole surface.

Hole cleaning generally involves three steps as listed below with specified repetitions depending on type of adhesive system, drilling method and cleaning equipment used:

(a) Repetitive cleaning of dust or debris by air (manual air pump or with compressed air*)
(b) Repetitive wire brushing (manual or mechanically) of hole wall to remove surface dust
(c) Repeating of step (a)

*When cleaning with compressed air, the air flow must be oil-free. Cleaning procedures vary for different qualified adhesive systems, drilling methods, and hole depths/rebar size combinations.

Detail instructions for cleaning procedures (e.g. drilling method, hole depth, rebar size, cleaning equipment used and number of repetitions at each step) are found in MPII, product ETA and/or IFU.

The concrete in which the PIR is to be installed may be dry, saturated or even partially or completely submerged at the time of installation. When installation in water-saturated or submerged concrete is required, check that the adhesive system selected is qualified and the PIR design has accommodated for such conditions. The qualifications and design considerations can be found in the product ETA.

Wet diamond core drilling will result in a damp drilled hole. Diamond cored-hole cleaning will generally involve sequential flushing until clear water exits, blowing the hole with compressed air to remove debris and water, and use of wire brush to mechanically scour the hole.

3.3.6. Selection of Adhesive System

The choice of appropriate qualified adhesive system and injection equipment is dependent on design requirements and jobsite conditions. The following are some considerations associated with adhesive selection:

(a) Can the adhesive be injected, and the rebar installed within the working time of adhesive?
(b) Is appropriate injection equipment available, including all necessary accessories to ensure correct dispensing and mixing in given time?
(c) Is the adhesive suitable (refer to ETA) for the concrete temperature, hole drilling method, hole orientation and moisture conditions?
(d) What mechanical effort or equipment is required to inject the adhesive and install bar into the adhesive filled hole within the working time of the adhesive?
(e) How long will the rebar be held in place during the curing time period?

For example, if a fast-curing adhesive is used for a large diameter, deep rebar installation, the time required to inject the adhesive may exceed the working time of the adhesive. It may become impossible to insert the rebar fully into the hole or the adhesive may not reach the required bond strength as the curing process has already started before the rebar is inserted. Table 5 provides a checklist for guidance in selection of the PIR adhesive.

Table 5. Checklist guidance for selection of PIR adhesive system

Factors	**Considerations**
Qualifications required (ETA issued based on)	a. EAD 330087 b. EAD 332402
Concrete strength class	______ (cylinder/cube)
Conditions of drilled hole	a. Dry b. Wet c. Water filled/flooded
Diameter and depth of drill hole	Hole diameter: _________ Hole depth: _______________
Direction of drill hole	a. downward b. horizontal c. overhead
Drilling method	a. hammer drilling b. rock-drilling/pneumatic drilling c. diamond drilling (with / without hole roughening)
Hole cleaning	a. as per MPII b. unable to clean as per MPII due to site conditions
Installation temperature	Temperature of concrete at time of installation: ___________ °C
Expected working time and cure time	Working time: _______ (mins), Full cure time: _______ (mins)
Concrete temperature in service condition	Min temperature/ max temperature: _________/___________ °C Max long term temperature: ____________________ °C
Fire rating of the element of structure	R: _____________ (mins) (‘0’ if non-fire-rated)
Durability, expected working life	____________ (years)

3.3.7. Injection of Adhesive System

The objective of adhesive injection is to dispense the adhesive in the borehole safely, correctly, and in a timely manner to achieve a void-free installation. Air voids reduce the effective bond area, impacting the load performance of a PIR and failing to provide the required corrosion protection. Additionally, air voids can lead to dangerous uncontrolled ejection of the adhesive from the hole as air is forced out of the adhesive matrix during rebar insertion.

Note : All prescribed personal protective equipment (PPE), with particular attention for skin and eye protection, MUST be worn during handling and use of PIR adhesive. Follow all instructions in MPII, relevant ETA and/or product IFU.

Dispensers are typically specific for the type of adhesive and users should refer to the respective MPII and/or product ETA. Use of dispensers incompatible with the adhesive may lead to improper mixing, loss of PIR performance, damage to adhesive cartridge or foil pack and may cause harm to the installer.

Injection of adhesive must strictly follow the procedures in MPII, product ETA and/or IFU. The following are recommended for the proper injection of adhesive:

(a) **Check depth of hole before injecting adhesive.**
This can be determined by inserting a marked rebar or wire rod into the cleaned hole. At this point, it is advisable to test the fit of intended PIR in the hole before injecting adhesive.

(b) **Adhesive must be thoroughly mixed.**
The adhesive components, typically supplied in two-part cartridges, must be thoroughly mixed to achieve a completely homogeneous mixture when dispensed into the hole. The mixing nozzle supplied with the product adhesive is specifically applicable for that product's purpose and should not be interchanged. Also, the nozzle and its components should not be tampered with. When using a new adhesive cartridge, follow the MPII and product ETA to discard the initial portion of dispensed adhesive. This ensures that only thoroughly mixed adhesive is injected into the hole from the start. The above are general steps for the adhesive mixing. Refer to the respective product ETA for the detailed steps on ensuring the adhesive is thoroughly mixed.

(c) **Inject starting from bottom of hole.**
Injection must start from the bottom of the hole, with the mixing nozzle retracted gradually while injecting adhesive until the hole is approximately two-thirds full. If the supplied mixing nozzle and accessories are too short to reach the bottom of the hole, extensions will be required. Refer to the manufacturer's recommendations, MPII, and product ETA for the actual volume to fill based on hole depth, diameter, and PIR size.

(d) **Minimize air voids using plugs and extensions.**
During adhesive injection, it is recommended to use piston plugs and extension tubes to achieve hole filling with minimal air voids in the adhesive matrix. These aids help the installer control the injection process, significantly improve injection quality, reduce wastage, and enhance efficiency, especially when injecting into deeper holes. The use of extensions and piston plugs is also necessary for overhead injection to ensure complete hole filling and prevent adhesive from dripping out during injection.

During the injection process, the installer must pay attention to working time of the adhesive based on temperature of the base material so that the rebar can be inserted in time. The mixing nozzle and accessories should be replaced with new ones if the residence time of unspent adhesive in them is beyond the working time.

3.3.8. Rebar Preparation and Setting

The rebar being installed should be clean, dry, free of oil, rust or other residue. The desired embedment depth should be clearly marked (e.g. with adhesive tape) (see Figure 12).

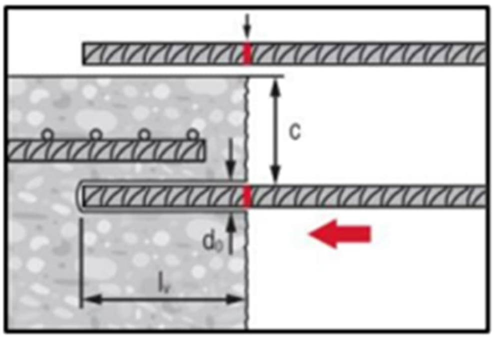


Figure 12. Example of marking for rebar’s desired embedment depth

It is advisable to test fit the rebar in the hole prior to injecting the adhesive. After injecting and filling the hole with the correct volume of adhesive, the rebar should be pushed into the filled hole with a slow twisting motion to prevent expulsion of adhesive during insertion and to ensure that the adhesive completely fills the gap between the rebar and hole surface (see Figure 13).

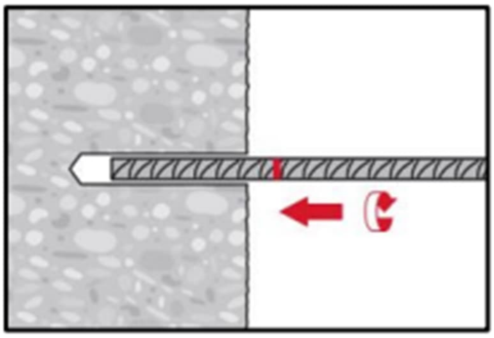


Figure 13. Rebar insertion into hole with slow twisting motion until the desired embedment depth is reached

A proper installation shall be observed under the following conditions:

(a) The desired PIR embedment depth is reached without sudden expulsion of the adhesive part way indicating presence of air-voids in the adhesive matrix.

(b) When the rebar is fully inserted to the required embedment depth, some excess adhesive should flow out of the drilled hole. This indicates that the hole is completely filled with adhesive. If no adhesive emerges after the rebar is fully inserted, there may be insufficient adhesive in the hole. In this case, the installation may be repeated while within the working time limit of the adhesive by removing the rebar, refilling the hole with adhesive, and re-inserting the rebar. If the maximum working time of the adhesive has elapsed, the installation should be abandoned and replaced with a new PIR.

(c) When installing rebar overhead, provisions should be taken to collect adhesive which may be expelled out of the hole (e.g. using catch containers). Also, for overhead installations, the rebar should be supported and secured from displacement or falling out during the working time period. This can be done by wedges or other supports to the rebar (see Figure 14).

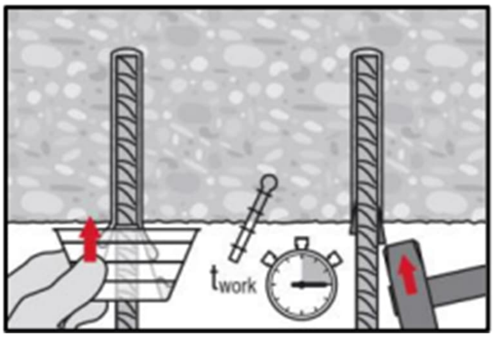


Figure 14. Drip containers and rebar wedges for safe overhead installation and securing of overhead PIR during curing period

(d) Observe working time period. Minor adjustments to the rebar may be performed during this time.

(e) Observe the initial cure time. The rebar should not be adjusted during this period to full cure. Full load can only be applied after full curing time has elapsed.

Chapter 4

Quality Control of Post-Installed Reinforcement Works

4.1. SUPERVISION AND INSPECTION

Site supervisors, appointed by the QP (Supervision), should oversee PIR works. These site supervisors must be competent in PIR installations and fully aware of the potential consequences of incorrect installation as prescribed in Section 3.1. For guidance on supervision requirements and the preparation of the site supervision plan, users may refer to the 'Guide Book for Site Supervision Plan' jointly published by BCA, IES and ACES.

The supervision of PIR works is crucial during drilling, hole cleaning, and rebar installation. After the curing period and before lapping further rebar or loading the PIR, inspection of the PIR works is essential. The inspector should carefully observe any rotation, movement, deformation, cracking, or other damage to the PIR. If the suitability of the installed PIR is uncertain, further rebar should not be installed.

It is important to document the inspection findings in site inspection reports to verify that the PIR has been correctly installed according to specifications and approved plans, and is in an acceptable condition for subsequent loading. Quality control involves actively managing the construction process and implementing corrective actions when necessary. For quality control of PIR installation, Table 6 provides a recommended checklist for site supervision and inspection.

Note: The checklist in Table 6 is for recommendation only and can vary between projects. The QP, who has statutory responsibility for the structural safety of the building works, should determine the appropriate supervision and inspection measures for the PIR works.

4.2. ON-SITE TESTING

PIR systems installed in accordance with the manufacturer’s instructions and within the scope of the relevant ETA do not require on-site testing for performance verification. The performance of PIR systems with ETA is already assessed and qualified with the relevant EAD referred in the ETA.

On-site testing primarily serves to validate installation quality and ensure compliance with correct procedures, rather than to assess the characteristic performance of the PIR system or to compare products for approval. This is because crucial PIR characteristics such as displacements, creep behaviour, durability, performance under short-term and long-term temperatures, corrosion protection, fire performance, and long-term stability cannot be adequately assessed through on-site testing.

It is important to note that the quality of installation significantly influences the performance of PIR systems. In Singapore, where a certified installer scheme is absent, on-site testing becomes necessary to validate the installation quality of PIR systems.

Table 6. Site supervision and inspection checklist for PIR

Supervision and Inspection Checklist for Post-Installed Reinforcement (PIR)		**Value (if any)**	**Check verification**		
			Yes	**No**	**N.A.**
1.0	**Drawing, specification and method statement**				
2.0	**PIR installer competent and trained**				
3.0	**Pre-installation and drilling checks**				
3.1	Existing member details (level, dimensions etc.)				
3.2	PIR location (level, cover, spacing) and details (diameter, length etc.) as per approved plan				
3.3	Detection/scanning for existing rebar/other objects				
3.4	Concrete surface preparation (as per MPII, ETA)				
3.5	Drilling method as per specification/requirement, MPII, ETA and/or IFU				
3.6	Drilling depth and diameter of borehole				
3.7	Borehole roughening and cleaning as per MPII, ETA and/or IFU				
4.0	**Adhesive check**				
4.1	Qualified PIR adhesive used as per approved plan				
4.2	Adhesive condition (storage) and expiry				
4.3	Temperature and surface condition prior to injection				
4.4	Tools and accessories used and adhesive dispensed as per MPII to avoid air voids				
4.5	Required volume of adhesive				
5.0	**PIR check**				
5.1	PIR diameter and length as per approved specification				
5.2	Rebar inserted as per MPII, ETA and/or IFU				
5.3	Rebar embedment depth and perpendicularity				
5.4	Provision for securing of rebar (overhead/inclined installation)				
5.5	Adhesive working and curing times observed				
5.6	On-site pullout testing (based on QP direction)				
6.0	**New concrete / rebar checks as per approved plan**				
Note	**All health and safety, environment, formwork, concreting and other checks as stipulated in the site supervision plan must be performed as per project scope**				

4.2.1. Frequency of Testing

Given the absence of a universal standard for on-site PIR testing, reference can be made to the guidance in NA to SS EN 1992-4 for test regimes that align with local industry needs. The recommended testing frequency, as summarized in Table 7 with reference to NA to SS EN 1992-4, can be considered.

It is important to note that the recommended testing regime is preliminary guidance, and requirements for the testing regime can vary between projects. The QP, who has statutory responsibility for the structural safety of the building works, should determine the appropriate sampling rates.

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.

4.2.2. On-site Test Load and Acceptance Criteria

The PIR should be tested to a recommended tensile load 1.5 times the characteristic action or otherwise specified by the QP. The testing load should always be less than $0.87f_{yk}$.

The quality of the PIR installation is accepted if the target test load can be achieved without significant or sudden load drops, and no observable signs of separation/displacement or damage to the rebar or surrounding concrete material. Otherwise, the test may be deemed as failed. A small, gradual load drop may be observed when the applied test loading is halted due to relaxation and distribution of stresses into the base material. This does not indicate failure, and the target test load can be reached again with a small re-application of load from the test equipment.

Test failures may indicate unsatisfactory installation processes or other non-compliances. If one PIR fails, investigate the reason for the failure and double the frequency of testing in that discrete area. Should replacement of the installed PIR be required, the works should be carried out by a competent installer. The procedures and specification of replacement and re-installation should be approved by the QP before conducting the PIR replacement works.

4.3. PERSON CONDUCTING PIR TEST (TESTER) AND INFORMATION TO BE PROVIDED

It is recommended as good site practice to perform the on-site testing by a SAC-accredited laboratory as prescribed in the 'Guide Book for Site Supervision Plan'. The tester should understand the workflow and potential failure modes of the PIR system. This will significantly improve the test and provide constructive feedback to the QP. A method statement for the test procedure should be approved by the QP prior to execution of the PIR test.

The tester should first confirm with the test requester that the PIR is installed in the location specified in the approved plan. Additionally, they should verify that the PIR installation complies with the relevant MPII, product ETA, and/or IFU guidelines. The following information should be provided to the tester by the test requester or QP before commencement of any testing:

(a) Test objective –validation of installation quality (e.g. by tests) or others such as determination of allowable resistance (e.g. special conditions etc.).
(b) Designation of PIR to be tested (e.g. type/brand of PIR adhesive used).
(c) Number of PIR to be tested.
(d) Test load required.
(e) Installation details (date of installation, depth of hole, size of rebar).
(f) Base material – grade and strength if known.
(g) Direction of the pull test (vertical upwards or vertical downwards, horizontal).
(h) Geometry of the installation (e.g. edge distances, spacing).
(i) Details of site accessibility if necessary (e.g. working on hoists, gondola or raised platforms etc).
(j) If testing involves work at height or other special site conditions (e.g. underwater).

4.4. TEST REPORT

Test reports should be documented for reference and audits as per the site supervision plan. The test report should contain details to determine if test objectives have been achieved. Typical details and supplemented information to be recorded are as follows (additional details may be required based on circumstances of the installation and testing conditions):

(a) Administrative details – Project, date of test, report reference number.
(b) Test requesters particulars – company name, person, contact info, position etc.
(c) Name and company of the installer.
(d) Name and company of the site supervisor of the PIR works.
(e) Name and company of the tester.
(f) Details of the installed PIR – manufacturer, type, size of PIR.
(g) Test location and condition – location of each PIR, spacing and cover.
(h) Base material – type and strength, thickness, condition.
(i) Test objective – required test load, displacement etc.
(j) Installation details – drilling method, hole diameter, hole depth, hole direction, cleaning method, observation of working and cure times.
(k) Test equipment – type of test equipment, manufacturer, load capacity, date of last calibration and certification body, loading frame if used.
(l) Test results – load applied, observations, failure modes where applicable.
(m) Comment statement that the tested PIRs have (or have not) met test objectives.
(n) Signature of tester, installer, supervisor, test requester or QP and/or other witnesses of the test.

Chapter 5

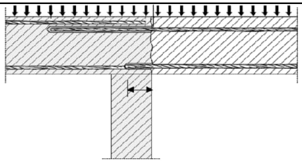
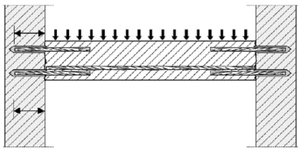
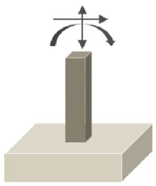
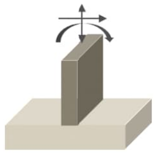
Design Guidelines for Post-Installed Reinforcement

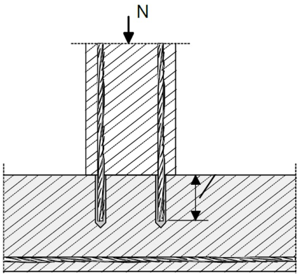
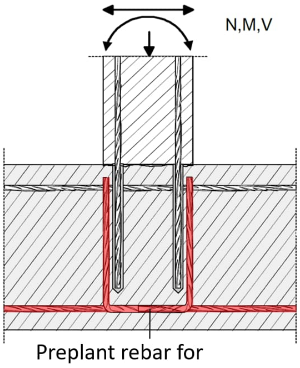
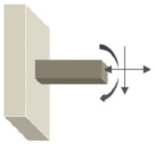
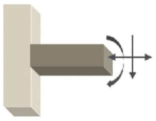
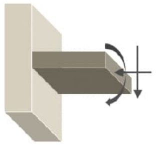
5.1. DESIGN ANCHORAGE LENGTH METHOD AND DESIGN RESISTANCE METHOD

PIR can be designed using either the design anchorage length method according to SS EN 1992-1-1 or the design resistance method as per EOTA TR 069. Each method has specific limited applications and assumptions. Table 8 presents a comparison of both design methods, with their applications explicitly limited to the scenarios prescribed in the table only. The two methods are not interchangeable.

The design anchorage length method is typically used for simply supported connections. However, it can also be applied to moment-resisting connections if existing rebars are available for lapping with the PIR, substantiated by as-built information and on-site verification. In contrast, the design resistance method is specifically for moment-resisting connections and does not require existing rebars for lapping.

Table 8. Comparison of design anchorage length method and design resistance method

Difference	Design anchorage length method		Design resistance method	
Adhesive technical specification	EAD 330087		EAD 330087 **and** EAD 332402	
Design document	- Static action: SS EN 1992-1-1 - Seismic action: SS EN 1998-1		EOTA TR 069	
Application	(a) Overlapping joint with existing rebar		Moment-resisting connections (rigid connections), without the need for existing rebar for lapping.	
	(b) Anchoring of the rebar at the end support designed as simply supported		(a) Column to foundation/slab	
			(b) Wall to foundation/slab	

	(c) Anchoring of rebar stressed primarily in compression (d) Anchoring of rebar to cover the line of the acting tensile force, in the presence of existing rebar for lapping	  Preplant rebar for future PIR lapping. **This is not a shear link.* (Images above are adopted from EAD 330087 Figure 1.2 to 1.5)	(c) Beam to wall (d) Beam to column (e) Slab to wall	   (Images above are adopted from EOTA TR 069 Figure 1.1.)
Load transfer mechanism	Bond transfer		Utilisation of tensile concrete strength	
Failure mode	Tension: Steel failure, pull-out-splitting		Tension: Steel failure, concrete cone, bond-splitting	
Provision to base material	Uncracked concrete*		Cracked and uncracked concrete#	
Basic design value of bond strength	Deduced by calculation (Based on SS EN 1992-1-1 Eq. 8.2)		Tested and approved	
Design results	Design anchorage length		Design resistance	
Minimum anchorage/lap length ($l_{b,min}$)	Anchorages in tension: $l_{b,min} \geq \alpha_{lb}.\max\{0.3l_{b,rqd}; 10\phi; 100mm\}$ Anchorages in compression: $l_{b,min} \geq \alpha_{lb}.\max\{0.6l_{b,rqd}; 10\phi; 100mm\}$ lap splicing connection: $l_{o,min} \geq \alpha_{lb}.\max\{0.3\alpha_6 l_{b,rqd}; 15\phi; 200mm\}$		Anchorages in tension: $l_{b,min} \geq \alpha_{lb}.\max\{0.3l_{b,rqd}; 10\phi; 100mm\}$ Anchorages in compression: $l_{b,min} \geq \alpha_{lb}.\max\{0.6l_{b,rqd}; 10\phi; 100mm\}$	

*The pull-out resistance in cracked concrete between a PIR and cast-in rebar is checked as per EAD 330087. If necessary, the minimum anchorage length ($l_{b,min}$) of the PIR shall be increased by multiplying it with an amplification factor (α_{lb}). For further information, refer to Table 3 in Section 2.2 and Section 5.2.

#In general, it is conservative to assume that the concrete is cracked over its service life.

5.2. OVERVIEW OF DESIGN PROVISIONS IN SS EN 1992-1-1

The design anchorage length (l_{bd}) of PIR with ETA under EAD 330087 can be calculated using the same design principles as those under Chapter 8 in SS EN 1992-1-1 for cast-in rebar. This can be rearranged into the following form:

$$l_{bd} = \alpha_2 \alpha_3 \alpha_5 l_{b,rqd} \geq l_{b,min} \qquad \text{[SS EN 1992-1-1 Cl. 8.4.4]}$$

where,

α_2 = Coefficient for the effect of minimum concrete cover to consider splitting failure, $0.7 \leq [1 - 0.15(c_d - \emptyset)/\emptyset] \leq 1.0$, refer to SS EN 1992-1-1 Table 8.2 for detail information

α_3 = Coefficient to account for confinement effects by transverse reinforcement (between 0.7 and 1.0), refer to SS EN 1992-1-1 Table 8.2 for detail information

α_5 = Coefficient to account for the effect of the transverse pressure (between 0.7 and 1.0), refer to SS EN 1992-1-1 Table 8.2 for detail information

$l_{b,rqd}$ = Basic anchorage length, $(\emptyset/4)(\sigma_{sd}/f_{bd,PIR})$

$l_{b,min}$ = Minimum anchorage length, maximum {30% (or 60%) of the basic anchorage length ($l_{b,rqd}$) for tension (or compression) case; 10ϕ; 100mm}

ϕ = Diameter of rebar

σ_{sd} = Design stress in the rebar associated with the considered design action

$f_{bd,PIR}$ = Design bond stress of PIR system under static loading, taken from the relevant ETA

The variables α_1 and α_4, which are irrelevant to PIR, have been removed from the equation for clarity. Additionally, the minimum anchorage length ($l_{b,min}$) must be multiplied by an amplification factor (α_{lb}) specified in the ETA to account for the difference between cast-in rebar and PIR in cracked concrete.

In the case of lap splicing connection, an additional coefficient α_6 ranging from 1.0 to 1.5 must be introduced to consider the influence of the percentage of the area of rebars that are lapped, in accordance with Equation 8.10 of SS EN 1992-1-1. The minimum anchorage length in this case shall be the maximum of {30% of the basic anchorage length ($l_{b,rqd}$) multiplied by the factor α_6; 15ϕ; 200mm}.

The calculation of the forces to be anchored shall adhere to the requirements outlined in section 9 of SS EN 1992-1-1, where applicable. This calculation should consider:

(a) Tension force in bottom reinforcement due to effect of shear;

(b) Tension force due to the assumed partial fixity in the top reinforcement; and

(c) Compliance of the assumed partial fixity with the result provided by the structural analysis of the connection.

5.3. DESIGN STEPS FOR DESIGN ANCHORAGE LENGTH METHOD TO SS EN 1992-1-1

The design steps for design anchorage length method, according to SS EN 1992-1-1 are summarised in Table 9.

Table 9. Design steps for design anchorage length method

Step	**Detail**	**Relevant Clauses in SS EN 1992-1-1**
1	Calculate the required PIR at the support based on the greater of:	
	(a) Minimum reinforcement areas:	
	Beams & Slabs: $A_{s,min} = 0.26(f_{ctm}/f_{yk})bd \geq 0.0013bd$	9.2.1.1(1)
	Columns: $A_{s,min} = 0.10N_{Ed}/f_{yd} \geq 0.002A_c$	9.5.2(2)
	Walls: $A_{s,vmin} = 0.002A_c$	9.6.2(1)
	(b) Reinforcement required to resist support moment and shear force (M_{Ed} and V_{Ed}), derived from structural analysis	
	(c) Tension force due to the assumed partial fixity	9.2.1.2(1), 9.2.1.4(1), 9.3.1.2(1) & (2)
	(d) Tension force due to effect of shear	9.2.1.3(2), 9.2.1.4(2)
2	Extract relevant information for the selected PIR system with ETA and conformity to EAD 330087, including: (a) Installation method (b) Values of α_{lb}, k_b, $f_{bd,PIR}$ etc.	From ETA
3	Calculate the design anchorage length:	
	(a) Tension & Compression: $l_{bd} = \alpha_2\alpha_3\alpha_5 l_{b,rqd} \geq l_{b,min}$	8.4.4(1)
	(b) Lapping: $l_o = \alpha_2\alpha_3\alpha_5\alpha_6 l_{b,rqd} \geq l_{o,min}$	8.7.3(1)
	(c) For lapping joint, it is necessary to verify the design anchorage length with the cast-in requirement.	
4	Check the minimum anchorage/lap length:	
	(a) Tension: $l_{b,min} \geq \alpha_{lb}.\max\{0.3l_{b,rqd}; 10\phi; 100\text{mm}\}$	8.4.4(1)
	(b) Compression: $l_{b,min} \geq \alpha_{lb}.\max\{0.6l_{b,rqd}; 10\phi; 100\text{mm}\}$	8.4.4(1)
	(c) Lapping: $l_{o,min} \geq \alpha_{lb}.\max\{0.3\alpha_6 l_{b,rqd}; 15\phi; 200\text{mm}\}$	8.7.3(1)
	*Default value for α_{lb} = 1.5, unless otherwise specified in ETA.	
5	The larger anchorage length calculated from either step 3 or 4 should be adopted as the PIR anchorage length.	

5.4. OVERVIEW OF DESIGN PROVISIONS IN EOTA TR 069

EOTA TR 069 provides the design of moment-resisting connections, without the need for existing rebar for lapping, based on the realistic bond-splitting performance of a PIR system. The design methodology involves establishing a hierarchy of strengths among the following resistances, with the lowest value taken as the design capacity:

(a) Resistance against steel yielding ($N_{Rd,y}$)
(b) Concrete cone break-out resistance ($N_{Rd,c}$)
(c) Bond-splitting resistance ($N_{Rd,sp}$)

The design resistance against steel yielding ($N_{Rd,y}$) is:

$$N_{Rd,y} = A_s f_{yk} / \gamma_{Ms}$$ [EOTA TR 069 Cl. 4.2]

where,
A_s = Cross-sectional area of rebar
f_{yk} = Characteristic yield stress of rebar
γ_{Ms} = Material safety factor for steel, 1.15

The design concrete cone break-out resistance ($N_{Rd,c}$) is:

$$N_{Rd,c} = N^0{}_{Rk,c} \frac{A_{c,N}}{A^0{}_{c,N}} \psi_{s,N} \psi_{ec,N} \psi_{re,N} \psi_{M,N} / \gamma_{Mc}$$ [EOTA TR 069 Cl. 4.3]

where,
$N^0{}_{Rk,c}$ = $k_1 f_{ck}^{0.5} l_b^{1.5}$
k_1 = 7.7 for cracked concrete, and 11.0 for uncracked concrete
f_{ck} = Characteristic cylinder compressive strength of concrete
l_b = Embedment length or anchorage length
$A_{c,N}$ = Actual projected area of the group of tensioned rebars, limited by overlapping of projected areas of adjacent bars and presence of edges
For single reinforcement, $(c_1+0.5s_{cr,N})(c_2+0.5s_{cr,N})$
For group reinforcement, $(c_1+s_1+0.5s_{cr,N})(c_2+s_2+0.5s_{cr,N})$
where, c_1 and c_2 represent the edge distances measured from the centre of the rebar, and s_1 and s_2 are the distances between rebars in orthogonal directions. For infinite edge distance (e.g. drilling into the existing RC wall), c_1 and c_2 may be replaced by $0.5s_{cr,N}$
$A°_{c,N}$ = Reference projected area for concrete cone failure, $s_{cr,N}^2$, where $s_{cr,N}$ is given in the relevant ETA
$\psi_{s,N}$ = Factor to account for the disturbance effect of distribution stress due to the edge of concrete members, $0.7+0.3(c/c_{cr,N}) \leq 1.0$, where c is the smallest edge distance measured from the centre of the rebar, and $c_{cr,N}$ is given in the relevant ETA
$\psi_{ec,N}$ = Factor to cater for the eccentricity between the point of application of tension force and the centre of gravity of rebars, $1/[1+2(e_N/s_{cr,N})] \leq 1.0$, where e_N is the eccentricity of the resulting tension force with reference to the centre of gravity of the tension rebars
$\psi_{re,N}$ = Shell spalling reduction factor for closely spaced reinforcement with an anchorage length of less than 100 millimetres, $0.5+(l_b/200) \leq 1.0$; the factor may be taken as 1.0 if the rebar spacing is ≥ 150mm
$\psi_{M,N}$ = Factor to consider the effect of compression stress resulting from moment-resisting actions the concrete cone capacity, $2.0-z/(1.5l_b) \geq 1.0$
γ_{Mc} = Material safety factor for concrete cone resistance, $\gamma_{inst}.\gamma_c$, where the installation factor γ_{inst} is given in the relevant ETA and $\gamma_c = 1.5$

The design bond-splitting resistance ($N_{Rd,sp}$) is:

$$N_{Rd,sp} = \tau_{Rk,sp} l_b \emptyset \pi / \gamma_{Msp} \qquad \text{[EOTA TR 069 Cl. 4.4]}$$

$$\begin{aligned} \tau_{Rk,sp} &= \eta_1 A_k (f_{ck}/25)^{sp1} (25/\emptyset)^{sp2} [(c_d/\emptyset)^{sp3} (c_{max}/c_d)^{sp4} + k_m K_{tr}] \left(\frac{7\emptyset}{l_b}\right)^{lb1} \Omega_{p,tr} \\ &\leq \tau_{Rk,ucr} \Omega_{cr} | \Omega_{p,tr}{}^{*} \psi_{sus} && \text{for } 7\phi \leq l_b \leq 20\phi \\ &\leq \tau_{Rk,ucr} (\frac{20\emptyset}{l_b})^{lb1} \Omega_{cr} | \Omega_{p,tr}{}^{*} \psi_{sus} && \text{for } l_b > 20\phi \end{aligned}$$

*In the case of cracked concrete, only Ω_{cr} applies and $\Omega_{p,tr}$ shall not be applied.

where,
l_b = Embedment length or anchorage length
ϕ = Diameter of rebar
γ_{Msp} = Material partial safety factor for improved bond-splitting resistance, $\gamma_{inst} \cdot \gamma_c$, where γ_{inst} is given in the relevant ETA and $\gamma_c = 1.5$
η_1 = Coefficient for bond condition, 1.0 for good condition and 0.7 for other cases
f_{ck} = Characteristic cylinder compressive strength of concrete
c_d = Minimum concrete cover, min $\{c_s/2; c_x; c_y\}$, refer to EOTA TR 069 Figure 4.1 for detail information
c_{max} = Maximum concrete cover, max $\{c_s/2; c_x\}$, refer to EOTA TR 069 Figure 4.1 for detail information; ratio c_{max}/c_d shall not be larger than 3.5
k_m = Factor for the effectiveness of transverse reinforcement, refer to EOTA TR 069 Figure 4.2 for detail information
K_{tr} = Normalized ratio to consider the amount of transverse reinforcement crossing a potential splitting surface, $n_t A_{st}/(n_b \phi s_b) \leq 0.05$, where:
n_t is the number of stirrup confinement legs crossing a potential splitting surface
A_{st} is the cross-sectional area of a transverse rebar
n_b is the number of anchored or lapped bars in a potential splitting surface
s_b is the spacing between confining stirrups
$\Omega_{p,tr}$ = Multiplication factor due to transverse pressure
= $1 - tanh[2p_{tr}/f_{cm}]$ for $f_{cm} \leq p_{tr} \leq 0$ (compression)
= $1 - 0.3p_{tr}/f_{ctm}$ for $0 \leq p_{tr} \leq f_{ctm}$ (tension)
f_{ctm} and f_{cm} shall be taken according to SS EN 1992-1-1 Table 3.1
p_{tr} is the transverse pressure perpendicular to the longitudinal axis of PIR
For cracked concrete, there would be no contribution from transverse pressure as it is not effective in confinement. Therefore, $p_{tr} = 0$ and $\Omega_{p,tr} = 1.0$
ψ_{sus} = Factor to account for the effects of sustained loads
= 1 for $\alpha_{sus} \leq \psi^0_{sus}$
= $\psi^0_{sus} + 1 - \alpha_{sus}$ for $\alpha_{sus} > \psi^0_{sus}$
ψ^0_{sus} is factor taken from the relevant ETA or assumed at 0.6
α_{sus} is the ratio of sustained actions to total actions considered at the ultimate limit state

The factor A_k and the exponents *sp1*, *sp2*, *sp3*, *sp4*, and *lb1* are product-dependent parameters given in the relevant ETA to EAD 332402. The upper limit of the bond-splitting resistance is determined by the pullout resistance in uncracked concrete ($\tau_{Rk,ucr}$) as specified in the ETA. The value $\tau_{Rk,ucr}$ is adjusted by the factor $\Omega_{cr} < 1.0$ if cracked concrete conditions apply and should be taken from the relevant ETA.

5.5. DESIGN STEPS FOR DESIGN RESISTANCE METHOD TO EOTA TR 069

The design steps for design resistance method, according to EOTA TR 069 are summarised in Table 10.

Table 10. Design steps for design resistance method

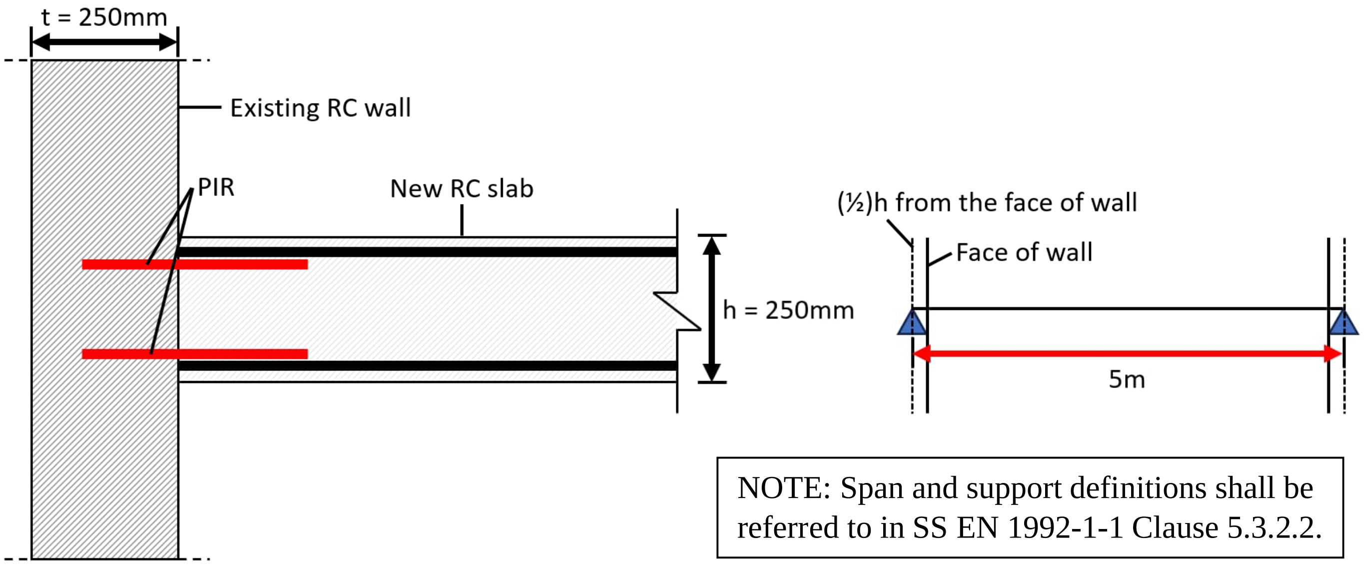
Step	Detail	Relevant Clauses in SS EN 1992-1-1 (EN) and EOTA TR 069 (TR)
1	Calculate the required PIR at the support based on the greater of: (a) Minimum reinforcement areas: Beams & Slabs: $A_{s,min} = 0.26(f_{ctm}/f_{yk})bd \geq 0.0013bd$ Columns: $A_{s,min} = 0.10N_{Ed}/f_{yd} \geq 0.002A_c$ Walls: $A_{s,vmin} = 0.002A_c$ (b) Reinforcement required to resist support moment and shear force (M_{Ed} and V_{Ed}), derived from structural analysis	 EN 9.2.1.1(1) EN 9.5.2(2) EN 9.6.2(1)
2	Extract relevant information for the selected PIR system with ETA and conformity to EAD 330087 and EAD 332402, including: (a) Installation method (b) Values of $\tau_{Rk,ucr}$, A_k, $sp1$, $sp2$, $sp3$, $sp4$, $lb1$, ψ^0_{sus}, k_1 (uncracked), k_1 (cracked), Ω_{cr}, γ_{inst}, $s_{cr,N}$, $c_{cr,N}$ etc.	From ETA
3	The design anchorage length according to EOTA TR 069 is the maximum length required to resist the design actions calculated for the failure modes of concrete breakout and bond-splitting, provided that the steel yielding strength is sufficient to resist the imposed stresses. As the resistances are functions of the anchorage length, the solution can be derived through a numerical iterative process. The use of software is recommended for efficiency in facilitating this trial-and-error process to determine the anchorage length. If hand calculation was utilised, the first-cut estimation of the anchorage length based on multiples of the minimum anchorage length can also be adopted. The resistance based on subsequent steps should be checked.	
4	Check the minimum anchorage length: (a) Tension: $l_{b,min} \geq \alpha_{lb}.\max\{0.3l_{b,rqd}; 10\phi; 100\text{mm}\}$ (b) Compression: $l_{b,min} \geq \alpha_{lb}.\max\{0.6l_{b,rqd}; 10\phi; 100\text{mm}\}$ *Default value for α_{lb} = 1.5, unless otherwise specified in ETA.	 EN 8.4.4(1) EN 8.4.4(1)

Step	**Detail**	**Relevant Clauses in SS EN 1992-1-1 (EN) and EOTA TR 069 (TR)**
5	Calculate the design resistance and compare it against the design actions (For PIR under tension): (a) Resistance against steel yielding ($N_{Rd,y}$) $N_{Rd,y} = A_s f_{yk} / \gamma_{Ms}$ (b) Concrete cone break-out resistance ($N_{Rd,c}$) $N_{Rd,c} = N^0{}_{Rk,c} \frac{A_{c,N}}{A^0{}_{c,N}} \psi_{s,N} \psi_{ec,N} \psi_{re,N} \psi_{M,N} / \gamma_{Mc}$ (c) Bond-splitting resistance ($N_{Rd,sp}$) $N_{Rd,sp} = \tau_{Rk,sp} l_b \emptyset \pi / \gamma_{Msp}$	TR 4.2 TR 4.3 TR 4.4
6	The larger anchorage length calculated from either step 3, 4 or 5 should be adopted as the PIR anchorage length.	
7	For PIR under compression, they are anchored at the front face of the existing member with the design anchorage length calculated according to design anchorage length method to SS EN1992-1-1. • Compression: $l_{bd} = \alpha_2 \alpha_3 \alpha_5 l_{b,rqd} \geq l_{b,min}$	EN 8.4.4(1)

5.6. DESIGN EXAMPLES FOR DESIGN ANCHORAGE LENGTH METHOD

All the examples presented in this section are focused on demonstrating PIR design. Other designs not relevant to PIR, such as deflection checks for serviceability, are not included.

Example 1: New simply supported RC slab connected to existing RC walls



NOTE: Span and support definitions shall be referred to in SS EN 1992-1-1 Clause 5.3.2.2.

Problem statement:

- A new 5m long (effective span) RC slab is proposed to span the void between two existing 250mm thick RC walls to create usable space.
- PIR is considered, and the new RC slab will be designed as simply supported.
- Based on these conditions, the design anchorage length method is adopted for the design.
- Scenario under Table 8, design anchorage length method application (b).

Design data:

- Existing RC wall: t = 250mm (C35/45)
- New RC slab: h = 250mm, b = 1000mm, l = 5m, cover = 25mm, d = 217mm (assume H16 bars)
- Concrete: Strength class C35/45, f_{ctm} = 3.2N/mm^2, $f_{ctk,0.05}$ = 2.2N/mm^2, γ_c = 1.5
- Reinforcement: f_{yk} = 500N/mm^2, γ_s = 1.15
- Permanent actions: g_k = 0.25x25 = 6.25kN/m^2
- Superimposed dead loads: g_k = 1.25kN/m^2
- Variable actions: q_k = 10kN/m^2
- Ultimate Limit State, $w = 1.35g_k + 1.5q_k$ = 1.35(6.25+1.25)+1.5x10 = 25.13kN/m^2

Adopted PIR parameters: (data from a sample of PIR system ETA as per EAD 330087)

- Drilling method = Hammer drilling in horizontal direction
- Installation temperature = 30°C
- In-service temperature = 30°C (long-term) and 40°C (short-term)
- Condition of base material = dry
- Design working life = 100 years
- Required seismic resistance = Yes
- Required fire resistance = Yes, 60 minutes
- $\alpha_{lb,100y}$ = 1.0, hence no increment required for the minimum anchorage length
- $k_{b,seis,100y}$ = 1.0, hence no reduction required for the bond strength
- $f_{bd,PIR,seis,100y}$ = 3.4N/mm^2

Structural analysis:

- Bending moment at midspan, $M_{Ed} = wl^2/8 = 25.13\text{x}5^2/8 = 79\text{kNm/m}$
- Shear at support, $V_{Ed} = wl/2 = 25.13\text{x}5/2 = 63\text{kN/m}$

Minimum reinforcement area:

- $A_{s,min} = 0.26(f_{ctm}/f_{yk})bd \geq 0.0013bd$ [SS EN 1992-1-1 Cl. 9.2.1.1(1)]
  $= 0.26(3.2/500)\text{x}1000\text{x}217 \geq 0.0013\text{x}1000\text{x}217$
  $= 362\text{mm}^2/\text{m} \geq 283\text{mm}^2/\text{m}$

Bottom rebar at mid span:

- $A_{s,rqd} = M_{Ed}/(0.9\text{d}f_{yk}/\gamma_s)$
  $= 79\text{x}10^6/(0.9\text{x}217\text{x}500/1.15)$
  $= 931\text{mm}^2/\text{m} > 362\text{mm}^2/\text{m}$

  Provide H16-200; $A_{s,prov} = 1005\text{mm}^2/\text{m}$

Bottom rebar at support (provided for PIR):

- At support, take half the calculated span reinforcement [SS EN 1992-1-1 Cl. 9.3.1.2(1)]
  $A_{s,rqd} = 0.5A_{s,rqd} = 0.5(931) = 466\text{mm}^2/\text{m} > 362\text{mm}^2/\text{m}$

  For practicality, select PIR of same diameter as mid-span reinforcement.

  Provide bottom PIR H16-200; $A_{s,prov} = 1005\text{mm}^2/\text{m}$

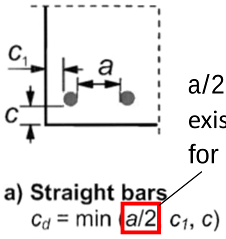
NOTE: In this example, the provided anchored reinforcement is more than the minimum requirement.

- Following the 'shift rule' for members without shear reinforcement, the bottom bars should minimally anchor a force equal to M_{Ed}/z, where M_{Ed} is the design moment at the section at a distance equal to d from the face of the support, and z is the lever arm, taken as equal to $0.9d$
  [SS EN 1992-1-1 Cl. 9.2.1.3(2)]
  $M_{Ed} = w(0.5h+1.0d)\text{x}[l-(0.5h+1.0d)]/2 = 20.1\text{kNm/m}$

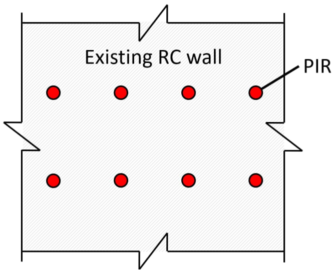
  $F_{Ed} = M_{Ed}/z = 20.1/(0.9\text{x}0.217) = 103\text{kN/m}$
  $A_{s,rqd} = F_{Ed}/(f_{yk}/\gamma_s) = 103\text{x}10^3/(500/1.15) = 237\text{mm}^2/\text{m} < A_{s,prov} = 1005\text{mm}^2/\text{m}$ [OK]

Design anchorage length for bottom PIR:

- The design anchorage length of bottom PIR is designed to the greatest of: (1) stresses of minimum rebar; (2) stresses of half the calculated span reinforcement (governing in this case); (3) stresses calculated from analysis.
- $F_{Ed} = 50\%\text{ x }M_{Ed}/z = 50\%\text{ x }79/(0.9\text{x}0.217) = 203\text{kN/m}$
- $\sigma_{sd} = F_{Ed}/A_{s,prov} = 203\text{x}10^3/1005 = 202\text{N/mm}^2$
- $l_{b,rqd,PIR} = (\phi/4)(\sigma_{sd}/f_{bd,PIR,seis,100y}) = (16/4)(202/3.4) = 238\text{mm}$ [SS EN 1992-1-1 Eq. 8.3]
- $\alpha_2 = 1-0.15(c_d-\phi)/\phi$ [SS EN 1992-1-1 Table 8.2]
  $= 1-0.15((200-16)/2-16)/16$
  $= 0.3 < 0.7$, Hence $\alpha_2 = 0.7$



a/2 is governing. The PIRs are drilling into the existing RC wall. c_1 and c are considered infinite for PIRs and therefore not governing in this case.



[SS EN 1992-1-1 Fig. 8.3]

- α_3 = 1.0 (influence of transverse reinforcement is neglected)
- α_5 = 1.0 (influence of transverse pressure is neglected)
- $l_{b,min,PIR}$ = $\alpha_{lb,100y} \cdot \max\{0.3 \cdot l_{b,rqd,PIR}; 10\varnothing; 100mm\}$ [SS EN 1992-1-1 Eq. 8.6]
  = 1.0 x max{0.3x238 = 72mm; 10x16 = 160mm; 100mm}
  = 160mm
- $l_{bd,PIR}$ = $\alpha_2 \alpha_3 \alpha_5 l_{b,rqd,PIR}$ [SS EN 1992-1-1 Eq. 8.4]
  = 0.7x1.0x1.0x238
  = 167mm

  Therefore,
- $l_{bd,PIR}$ = 170mm

NOTE: The design stress per reinforcement in this example is less than the f_{yd} because the provided reinforcement is more than the minimum requirement.

Provide anchorage length of 170mm for bottom PIR H16-200

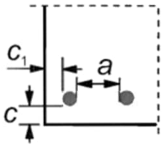
Top rebar at support (provided for PIR):

- At end support, partial fixity of 15% of midspan moment [SS EN 1992-1-1 Cl. 9.3.1.2(2)]
  $A_{s,rqd} = 0.15M_{Ed}/(0.9df_{yk}/\gamma_s) = 0.15x79x10^6/(0.9x217x500/1.15) = 140mm^2/m < 362mm^2/m$
  Use $A_{s,min} = 362mm^2/m$

Provide top PIR H13-200; $A_{s,prov}$ = 660mm²/m

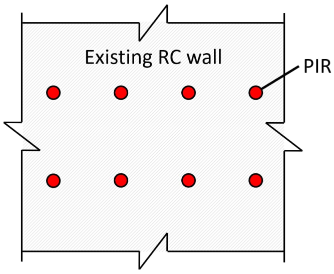
Design anchorage length for top PIR:

- The design anchorage length of top PIR is designed to the greatest of: (1) stresses of minimum rebar (governing in this case); (2) stresses calculated from analysis.
- σ_{sd} = f_{yd} x $A_{s,min}/A_{s,prov}$ = (500/1.15)(362/660) = 239N/mm²
- $l_{b,rqd,PIR}$ = $(\phi/4)(\sigma_{sd}/f_{bd,PIR,seis,100y})$ = (13/4)(239/3.4) = 229mm [SS EN 1992-1-1 Eq. 8.3]
- α_2 = $1-0.15(c_d-\phi)/\phi$ [SS EN 1992-1-1 Table 8.2]
  = 1-0.15((200-13)/2-13)/13
  = 0.1 < 0.7, Hence α_2 = 0.7



a) Straight bars
$c_d = \min(\boxed{a/2}, c_1, c)$

a/2 is governing. The PIRs are drilling into the existing RC wall. c_1 and c are considered infinite for PIRs and therefore not governing in this case.



[SS EN 1992-1-1 Fig. 8.3]

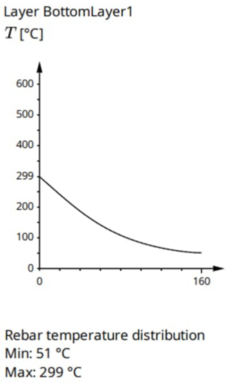
- α_3 = 1.0 (influence of transverse reinforcement is neglected)
- α_5 = 1.0 (influence of transverse pressure is neglected)
- $l_{b,min,PIR}$ = $\alpha_{lb,100y} \cdot \max\{0.3 \cdot l_{b,rqd,PIR}; 10\varnothing; 100mm\}$ [SS EN 1992-1-1 Eq. 8.6]
  = 1.0 x max{0.3x229 = 69mm; 10x13 = 130mm; 100mm}
  = 130mm
- $l_{bd,PIR}$ = $\alpha_2 \alpha_3 \alpha_5 l_{b,rqd,PIR}$ [SS EN 1992-1-1 Eq. 8.4]
  = 0.7x1.0x1.0x229
  = 161mm

  Therefore,
- $l_{bd,PIR}$ = 170mm

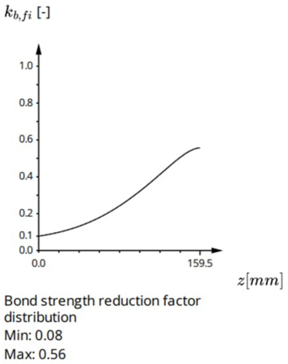
Provide anchorage length of 170mm for top PIR H13-200

Fire design:

- Fire exposure class is R60.
- The load on the connection may be reduced as per SS EN 1992-1-2 Clause 2.4.2(2) and (3)
  $F_{Ed,fi} = 0.7 \cdot F_{Ed} = 0.7x103 = 73kN$
- Material partial safety factors
  $\gamma_{M,fi} = 1.0$ [SS EN1992-1-2, Cl. 2.3]
- In this example, the temperature in the PIR decreases over the embedment length with increasing distance from the face of the wall. The temperature profile in the bottom PIR layer (closer to the fire) is calculated by finite element methods (FEM), and the output is shown in the figure below.



(a) Temperature profile (from FEM)



(b) Corresponding bond strength reduction factor (from FEM)

Fire design: Steel yield verification:

- Steel yield verification carried out under fire exposure considering the maximum temperature along the bar = 299°C
- $N_{Ed,fi} = \frac{F_{Ed,fi}}{n} = \frac{73}{5} = 15\text{kN}\ per\ bar$
- $k_s(\theta_{299°C}) = 1.0$ [SS EN 1992-1-2 Table 3.2a]
- $F_{yd,fi} = k_s(\theta_{max}) \cdot A_s \cdot f_{yk} / \gamma_{M,fi}$
  $= 1.0x201x500/1.0x10^{-3}$
  $=101kN > N_{Ed,fi} = 15kN$ [OK]

Fire design: Bottom rebar at support (PIR closest to fire):

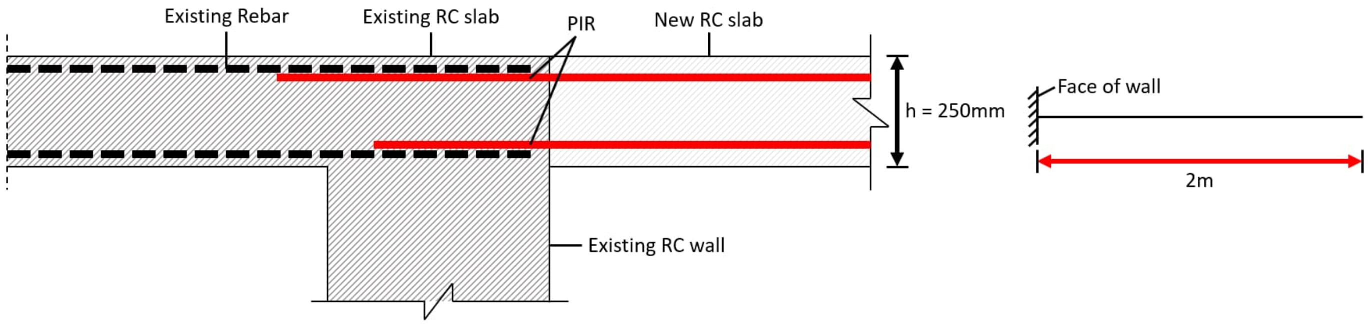
- The bond strength is calculated by integrating the PIR embedment length (x) at each corresponding temperature, and this process is repeated iteratively to find the overall bond resistance ($N_{Rd,fi}$) that equals the external action ($N_{Ed,fi}$). The use of software will significantly improve the efficiency of this design. In this example, the equivalent k_{fi} is 0.27 (the average value over the length of the PIR).
- $f_{bd,fi} = k_{fi}(\theta(x)) f_{bd,PIR} \gamma_c / \gamma_{M,fi}$
  $= 0.27x3.4x1.5/1.0$
  $= 1.4\ N/mm^2$
- $N_{Rd,fi} = \pi \varnothing f_{bd,fi} l_{bd,PIR,fi} / (\alpha_2 \alpha_3 \alpha_5)$
  Therefore,
  $l_{bd,PIR,fi} = (N_{Ed,fi} \alpha_2 \alpha_3 \alpha_5) / (\pi \varnothing f_{bd,fi})$
  $= (15 \times 10^3 x0.7x1.0x1.0) / (\pi x16x1.4)$
  $= 150mm < l_{bd,PIR}$

Provide anchorage length of 170mm for bottom PIR H16-200 forR60 fire exposure

Summary of design for PIR:

- Provide H13-200 with l_b = 170mm for top PIR
- Provide H16-200 with l_b = 170mm for bottom PIR

Example 2: New cantilever RC slab extension with lapping



Problem statement:

- A new cantilever 250mm thick RC slab is proposed to extend 2m from an existing 250mm thick RC slab to serve as a balcony.
- PIR is considered, with existing rebars available for lapping with the PIR.
- Based on these conditions, the design anchorage length method is adopted for the design.
- Scenario under Table 8, design anchorage length method application (a).

Design data:

- Existing RC slab: h = 250mm (C30/37), cover = 20mm, front cover = 20mm
- Existing RC slab reinforcement: H10-200 (top and bottom)
- New RC slab: h = 250mm, b = 1000mm, l = 2m, cover = 40mm, d = 205mm (assume H10 bars)
- Concrete: Strength class = C30/37, $f_{ctm} = 2.9\text{N/mm}^2$, $f_{ctk,0.05} = 2.0\text{N/mm}^2$, $\gamma_c = 1.5$
- Reinforcement: $f_{yk} = 500\text{N/mm}^2$, $\gamma_s = 1.15$
- Permanent actions: $g_k = 0.25\text{x}25 = 6.25\text{kN/m}^2$
- Superimposed dead loads: $g_k = 1.0\text{kN/m}^2$
- Variable actions: $q_k = 2.5\text{kN/m}^2$
- Ultimate Limit State, $w = 1.35g_k+1.5q_k = 1.35(6.25+1.0)+1.5\text{x}2.5 = 13.54\text{kN/m}^2$

Adopted PIR parameters: (data from a sample of PIR system ETA as per EAD 330087)

- Drilling method = Hammer drilling in horizontal direction
- Installation temperature = 30°C
- In-service temperature = 30°C (long-term) and 40°C (short term)
- Condition of base material = dry
- Design working life = 50 years
- Required seismic resistance = No
- Required fire resistance = No
- $\alpha_{lb,50y} = 1.0$, hence no increment required for the minimum anchorage length
- $k_{b,50y} = 1.0$, hence no reduction required for the bond strength
- $f_{bd,PIR,50y} = 3.0\text{N/mm}^2$
- Adopt cover/ edge distance of c_{min} = 40mm for PIR and c_{min} = 20mm for cast-in rebar

Structural analysis:

- Bending moment at support, $M_{Ed} = wl^2/2 = 13.54\text{x}2^2/2 = 27\text{kNm}$
- Shear at support , $V_{Ed} = wl = 13.54\text{x}2 = 27\text{kN}$

Minimum reinforcement area:

- $A_{s,min} = 0.26(f_{ctm}/f_{yk})bd \geq 0.0013bd$ [SS EN 1992-1-1 Cl. 9.2.1.1(1)]
  $= 0.26(2.9/500)\text{x}1000\text{x}205 \geq 0.0013\text{x}1000\text{x}205$
  $= 310\text{mm}^2/\text{m} \geq 267\text{mm}^2/\text{m}$

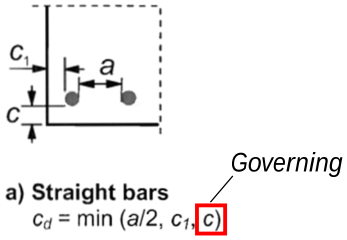
Top rebar at support (provided for PIR):

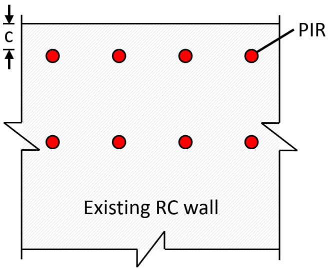
- $A_{s,rqd}$ $= M_{Ed}/(0.9df_{yk}/\gamma_s)$
  $= 27x10^6/(0.9x205x500/1.15)$
  $= 337mm^2/m > 310mm^2/m$

Provide top PIR H10-200; $A_{s,prov}$ = 392mm²/m

Design anchorage length for top PIR:

- Tension bars (top PIR) for cantilever beams or slabs should be anchored to develop the full design yield strength ($\sigma_{sd} = f_{yd}$) for robustness (ductility) requirement. Therefore:
- σ_{sd} $= f_{yd} = 500/1.15 = 435N/mm^2$
- $l_{b,rqd,PIR} = (\phi/4)(\sigma_{sd}/f_{bd,PIR,50y}) = (10/4)(435/3.0) = 363mm$ [SS EN 1992-1-1 Eq. 8.3]
- α_2 $= 1-0.15(c_d-\phi)/\phi$ [SS EN 1992-1-1 Table 8.2]
  $= 1-0.15(40-10)/10$
  $= 0.55 < 0.7$, Hence $\alpha_2 = 0.7$





[SS EN 1992-1-1 Fig. 8.3]

- α_3 = 1.0 (influence of transverse reinforcement is neglected)
- α_5 = 1.0 (influence of transverse pressure is neglected)
- α_6 = 1.5 [SS EN 1992-1-1 Table 8.3]
- $l_{o,min,PIR}$ $= \alpha_{lb,50y} \cdot \max\{0.3 \cdot \alpha_6 \cdot l_{b,rqd,PIR}; 15\phi; 200mm\}$ [SS EN 1992-1-1 Eq. 8.11]
  = 1.0 x max{0.3x1.5x363 = 164mm; 15x10 = 150mm; 200mm}
  = 200mm
- $l_{o,PIR}$ $= \alpha_2\alpha_3\alpha_5\alpha_6 l_{b,rqd,PIR}$ [SS EN 1992-1-1 Eq. 8.10]
  = 0.7x1.0x1.0x1.5x363
  = 382mm

  Therefore,
- $l_{o,PIR}$ = 382mm

Design anchorage length for top PIR using cast-in requirement:

- For practicality, cast-in rebar is typically designed to full design yield strength ($\sigma_{sd} = f_{yd}$). Therefore:
- σ_{sd} $= f_{yd} = 500/1.15 = 435N/mm^2$
- f_{bd} $= 2.25\eta_1\eta_2 f_{ctd} = 2.25x1x1x(2/1.5) = 3N/mm^2$ [SS EN1992-1-1 Eq. 8.2]
- $l_{b,rqd}$ $= (\phi/4)(\sigma_{sd}/f_{bd}) = (10/4)(435/3) = 363mm$ [SS EN 1992-1-1 Eq. 8.3]
- α_2 $= 1-0.15(c_d- \phi)/\phi$ [SS EN 1992-1-1 Table 8.2]
  $= 1-0.15(20-10)/10$
  $= 0.85 > 0.7$, Hence $\alpha_2 = 0.85$
- α_3 = 1.0 (influence of transverse reinforcement is neglected)
- α_5 = 1.0 (influence of transverse pressure is neglected)
- α_6 = 1.5 [SS EN 1992-1-1 Table 8.3]
- $l_{o,min}$ $= \max (0.3 \cdot \alpha_6 \cdot l_{b,rqd}; 15\phi; 200mm)$ [SS EN 1992-1-1 Eq. 8.11]
  = max{0.3x1.5x363 = 164mm;15x10=150mm; 200mm}
  = 200mm
- l_o $= \alpha_2\alpha_3\alpha_5\alpha_6 l_{b,rqd}$ [SS EN 1992-1-1 Eq. 8.10]
  = 0.85x1.0x1.0x1.5x363
  = 463mm

Therefore,

- l_o = 470mm

- $l_o > l_{o,PIR}$, therefore, the lap length of cast-in rebar is decisive and governing.
  $l_{v,PIR} = l_{o,PIR} + c_d = 470 + 20 = 490$mm

Provide anchorage length of 490mm for top PIR H10-200

<u>Bottom rebar at support (provided for PIR):</u>

- Use $A_{s,min} = 310$mm^2/m

Provide bottom PIR H10-200; $A_{s,prov} = 392$mm^2/m

<u>Design anchorage length for bottom PIR:</u>

- The design anchorage length of bottom PIR is designed to the greatest of: (1) stresses of minimum rebar; (2) stresses calculated from analysis <u>(governing in this case)</u>.
- $F_{Ed} = M_{Ed}/z = 27/(0.9\text{x}0.205) = 148$kN/m (compression)
- $\sigma_{sd} = F_{Ed}/A_{s,prov} = 148\text{x}10^3/392 = 378\text{N/mm}^2$
- $l_{b,rqd,PIR} = (\phi/4)(\sigma_{sd}/f_{bd,PIR,50y}) = (10/4)(378/3.0) = 315$mm [SS EN 1992-1-1 Eq. 8.3]
- $\alpha_2 = 1.0$ [SS EN 1992-1-1 Table 8.2]
- $\alpha_3 = 1.0$ [SS EN 1992-1-1 Table 8.2]
- $\alpha_5 = 1.0$ [SS EN 1992-1-1 Table 8.2]
- $l_{b,min,PIR} = \alpha_{lb,50y} \cdot \max\left(0.6 \cdot l_{b,rqd,PIR};\ 10\varnothing\ ;\ 100\text{mm}\right)$ [SS EN 1992-1-1 Eq. 8.7]
  $= 1.0 \text{ x } \max\{0.6\text{x}315=189;\ 10(10)=100;\ 100\text{mm}\}$
  $= 189$mm
- $l_{bd,PIR} = \alpha_2\alpha_3\alpha_5 l_{b,rqd,PIR}$ [SS EN 1992-1-1 Eq. 8.4]
  $= 1.0\text{x}1.0\text{x}1.0\text{x}315$
  $= 315$mm

Provide anchorage length of 320mm for bottom PIR H10-200

<u>Verification of minimum concrete cover c_{min} to EAD 330087 and ETA:</u>

- Without drilling aid, $c_{min} = \min\ \{30+0.06l_v;2\phi) = 59.4\text{mm} > 40\text{mm}$ [Not OK]
- With drilling aid, $c_{min} = \min\ \{30+0.02l_v;2\phi) = 39.8\text{mm} < 40\text{mm}$ [OK]

The use of drilling aid is recommended.

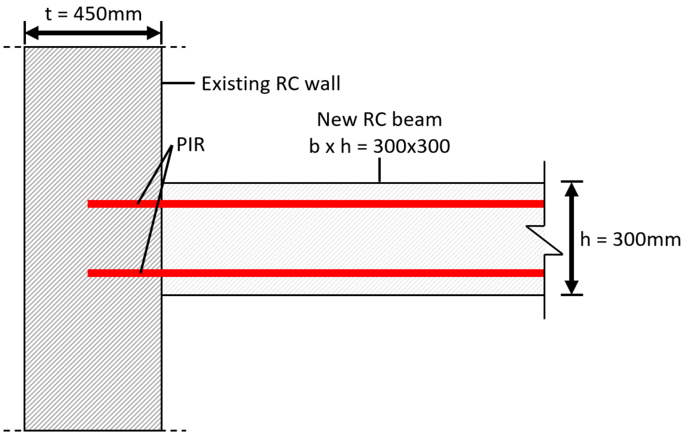
<u>Summary of design for PIR:</u>

- Provide H10-200 with drill depth 490mm and c = 40mm for top PIR
- Provide H10-200 with drill depth 320mm and c = 40mm for bottom PIR
- Hammer drilling with drilling aid to help maintain drilling angle is recommended.

5.7. DESIGN EXAMPLE FOR DESIGN RESISTANCE METHOD

The example presented in this section is focused on demonstrating PIR design. Other designs not relevant to PIR, such as deflection for serviceability, are not included.

Example 3: New cantilever RC beam connected to an existing RC wall



Problem statement:

- A new 1.2m long cantilever RC beam is proposed to extend from an existing 450mm thick RC wall.
- PIR is considered, and no existing rebars are available for lapping with the PIR.
- Based on these conditions, the design resistance method is adopted for the design.
- Scenario under Table 8, design resistance method application (c).

Design data:

- Existing RC wall: t = 450mm (C30/37)
- New RC beam: h = 300mm, b = 300mm, cover = 30mm, d = 263mm (assume H13 bars)
- Concrete: Strength class = C30/37, f_{ctm} = 2.9N/mm^2, $f_{ctk,0.05}$ = 2.0N/mm^2, γ_c = 1.5
- Reinforcement: f_{yk} = 500N/mm^2, γ_s = 1.15
- Factored design actions at the face of the support: V_{Ed} = 50kN, M_{Ed} = 30kNm
- Designed as cracked concrete

Adopted PIR parameters: (data from a sample of PIR system ETA as per EAD 330087 and EAD 332402)

- Drilling method = Hammer drilling in horizontal direction without drilling aid
- Installation temperature = 30°C
- In-service temperature = 30°C (long-term) and 40°C (short term)
- Condition of base material = dry
- Design working life = 50 years
- Required seismic resistance = No
- Required fire resistance = No
- $\alpha_{lb,50y}$ = 1.0, hence no increment required for the minimum anchorage length
- $k_{b,50y}$ = 1.0, hence no reduction required for the bond strength
- $f_{bd,PIR,50y}$ = 3.0N/mm^2
- $\tau_{Rk,ucr}$ = 12N/mm^2, A_k = 4.4, $sp1$ = 0.29, $sp2$ = 0.27, $sp3$ = 0.68, $sp4$ = 0.35, $lb1$ = 0.60, ψ^0_{sus} = 0.72, k_1 = 11 (uncracked), k_1 = 7.7 (cracked), Ω_{cr} = 1.04, γ_{inst} = 1.0, $s_{cr,N}$ = 3l_b, $c_{cr,N}$ = 1.5l_b

Minimum reinforcement areas:

- $A_{s,min} = 0.26(f_{ctm}/f_{yk})bd \geq 0.0013bd$ [SS EN 1992-1-1 Cl. 9.2.1.1(1)]
  $= 0.26(2.9/500) \times 300 \times 263 \geq 0.0013 \times 300 \times 263$
  $= 119\text{mm}^2 \geq 103\text{mm}^2$

PIR in the tension zone (top rebars):

- Force per rebar: $F_{Ed} = M_{Ed}/(n.z)$ (assume 3 bars for top layer)
  $= 30 \times 10^3/(3 \times 237)$
  = 43kN (or 127kN for the top layer)
- $A_{s,rqd} = 127 \times 10^3/(500/1.15)$
  $= 292\text{mm}^2 > 119\text{mm}^2$
- Steel yield verification: $N_{Rd,y} = A_s.f_y/\gamma_s$ [EOTA TR 069 Eq. 4.2]
  $= 132 \times 500/1.15 \times 10^{-3}$
  = 58kN > 43kN [OK]

The design anchorage length according to EOTA TR 069 is the maximum length required to resist the design actions calculated for the failure modes of concrete breakout and bond-splitting, provided that the steel yielding strength is sufficient to resist the imposed stresses. As the resistances are functions of the anchorage length, the solution can be derived through a numerical iterative process. The use of software is recommended for efficiency in facilitating this trial-and-error process to determine the anchorage length. Nevertheless, a first-cut estimation of the anchorage length based on multiples of the minimum anchorage length can also be adopted.

Check minimum anchorage length (top rebars):

- The minimum anchorage length for tension bars (top PIR) in cantilever beams or slabs should be calculated based on full design yield strength ($\sigma_{sd} = f_{yd}$) for robustness (ductility) requirement. Therefore:
- $l_{b,min,PIR} = \alpha_{lb,50y} \cdot \max(0.3 \cdot l_{b,rqd,PIR}; 10\emptyset; 100\text{mm})$ [SS EN 1992-1-1 Eq. 8.7]
  where,
  $\alpha_{lb,50y} = 1.0$,
- $l_{b,rqd,PIR} = (\phi/4)(\sigma_{sd}/f_{bd,PIR,50y}) = (13/4)(500/1.15)/3 = 471\text{mm}$ [SS EN 1992-1-1 Eq. 8.3]
- $l_{b,min} = 1.0 \times \max(0.3 \times 471; 10\emptyset; 100\text{mm})$
  $= \max(141; 130; 100\text{mm}) = 141\text{mm}$, provide extra 40% for the anchorage length,
  = 200mm

Top layer: Provide 3 numbers of H13 ($A_{s,prov} = 396\text{mm}^2 > A_{s,rqd} = 292\text{mm}^2$) with anchorage length 200mm (to further verify in next steps)

Concrete cone break-out verification (top rebars):

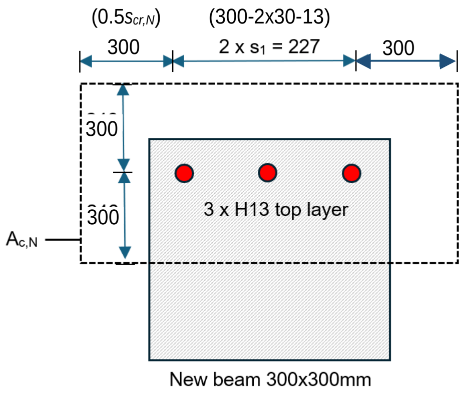
- $N_{Rd,c} = N^0_{Rk,c} \cdot \frac{A_{c,N}}{A^0_{c,N}} \cdot \Psi_{s,N} \cdot \psi_{ec,N} \cdot \psi_{re,N} \cdot \frac{\psi_{M,N}}{\gamma_{Mc}}$ [EOTA TR 069, Eq. 4.3]

  where,
- $N^0_{Rk,c} = k_1 \cdot \sqrt{f_{ck}} \cdot l_b^{1.5}$ ($k_1 = k_{cr,N} = 7.7$) [EOTA TR 069, Eq. 4.4]
  $= 7.7 \times \sqrt{30} \times 200^{1.5} \times 10^{-3}$
  = 119kN

  Note: k_1 is given in the corresponding product ETA obtained in accordance with EAD 332402

- $A^0_{c,N} = s_{cr,N} \cdot s_{cr,N} = (3 \cdot 200) \cdot (3 \cdot 200)$ [EOTA TR 069, Eq. 4.5]
  $= 360{,}000mm^2$

- $A_{c,N} = (2 \cdot 0.5 s_{\mathrm{cr,N}}) \cdot (0.5 s_{\mathrm{cr,N}} + 2 s_1 + 0.5 s_{\mathrm{cr,N}})$
  $= (2 \times 300) \cdot (300 + 227 + 300)$
  $= 496{,}200 mm^2$



The PIRs are drilled into the existing RC wall. The edge distances are considered infinite for PIRs and therefore not governing in this case.

- $\psi_{\mathrm{s,N}} = 1.0$ no influence of edges [EOTA TR 069, Eq. 4.6]
- $\psi_{\mathrm{ec,N}} = 1.0$ no eccentricity [EOTA TR 069, Eq. 4.7]
- $\psi_{\mathrm{re,N}} = 1.0$ no surface reinforcement reduction [EOTA TR 069, Eq. 4.8]

- $\psi_{M,N} = 2.0 - z / (1.5 \cdot l_b)$ [EOTA TR 069, Eq. 4.9]
  $= 2.0 - 237 / (1.5 \cdot 200)$
  $= 1.21$

Hence,

- $\mathrm{N_{Rd,c}} = 119 \mathrm{x} \frac{496{,}200}{360{,}000} \mathrm{x} 1.0 \mathrm{x} 1.0 \mathrm{x} 1.0 \mathrm{x} \frac{1.21}{1.5}$
  $= 132\ kN > 127\ kN$ $[OK]$

<u>*Bond-splitting verification (top rebars):*</u>

- $\mathrm{N_{Rd,sp}} = \tau_{\mathrm{Rk,sp}} \cdot \mathrm{l_b} \cdot \emptyset \cdot \pi / \gamma_{Msp}$ [EOTA TR 069, Eq. 4.10]

where,

- $\tau_{\mathrm{Rk,sp}} = \eta_1 \cdot \mathrm{A_k} \cdot \left(\frac{\mathrm{f_{ck}}}{25}\right)^{\mathrm{sp1}} \cdot \left(\frac{25}{\emptyset}\right)^{\mathrm{sp2}} \cdot \left[\left(\frac{\mathrm{c_d}}{\emptyset}\right)^{\mathrm{sp3}} \cdot \left(\frac{\mathrm{c_{max}}}{\mathrm{c_d}}\right)^{\mathrm{sp4}} + \mathrm{k_m} \cdot \mathrm{K_{tr}}\right] \cdot \left(\frac{7\emptyset}{\mathrm{l_b}}\right)^{\mathrm{lb1}} \cdot \Omega_{\mathrm{p,tr}}$
  $\leq \tau_{\mathrm{Rk,ucr}} \cdot \Omega_{\mathrm{cr}} | \Omega_{\mathrm{p,tr}}{}^{*} \cdot \psi_{\mathrm{sus}}$ [EOTA TR 069, Eq. 4.11]

  Factors A_k, *sp1, sp2, sp3, sp4*, $\tau_{\mathrm{Rk,ucr}}$, Ω_{cr} and *lb1* are taken from the product ETA. For cracked concrete, there would be no contribution from transverse pressure as it is not effective in confinement. Therefore, $p_{tr} = 0$ and $\Omega_{p,tr} = 1.0$

  As the PIRs are drilled into the existing RC wall, the edge distances are considered infinite for PIRs and therefore not governing in this case. c_d and $c_{max} = c_s/2$ = (300-2x30-3x13)/(2x2) = 50mm.

  $$\tau_{\mathrm{Rk,sp}} = 1.0 \mathrm{x} 4.4 \mathrm{x} \left(\frac{30}{25}\right)^{0.29} \mathrm{x} \left(\frac{25}{13}\right)^{0.27} \mathrm{x} \left[\left(\frac{50}{13}\right)^{0.68} \mathrm{x} \left(\frac{50}{50}\right)^{0.35} + 0\right] \mathrm{x} \left(\frac{7 \mathrm{x} 13}{200}\right)^{0.6} \mathrm{x} 1.0$$
  $= 8.6\ \mathrm{N/mm^2}$
  $\leq 12 \times 1.04 \cdot 1.0 = 12.5\ \mathrm{N/mm^2}$ [OK]

- $\mathrm{N_{Rd,sp}} = 8.6 \mathrm{x} 200 \mathrm{x} 13 \cdot \frac{\pi}{1.5} \times 10^{-3} = 46.8\ \mathrm{kN} \geq 43 \mathrm{kN}$ [OK]

Design anchorage length for bottom PIR:

- The design anchorage length of bottom PIR is designed to the greatest of: (1) stresses of minimum rebar; (2) stresses calculated from analysis (governing in this case).
- Force per rebar: F_{Ed} $= M_{Ed}/(n.z)$ (assume 3 bars for bottom layer)
  $= 30x10^3/(3x237)$
  $= 43kN$ (compression)
- σ_{sd} $= F_{Ed}/A_{s,prov} = 43x10^3/132 = 326N/mm^2$
- $l_{b,rqd,PIR} = (\phi/4)(\sigma_{sd}/f_{bd,PIR,50y}) = (13/4)(326/3.0) = 354mm$ [SS EN 1992-1-1 Eq. 8.3]
- α_2 $= 1.0$ [SS EN 1992-1-1 Table 8.2]
- α_3 $= 1.0$ [SS EN 1992-1-1 Table 8.2]
- α_5 $= 1.0$ [SS EN 1992-1-1 Table 8.2]
- $l_{b,min,PIR}$ $= \alpha_{lb,50y} \cdot \max(0.6 \cdot l_{b,rqd,PIR}; 10\emptyset; 100mm)$ [SS EN 1992-1-1 Eq. 8.7]
  $= 1.0 \text{ x } \max\{0.6x354=213; 10(13)=130; 100mm\}$
  $= 213mm$
- $l_{bd,PIR}$ $= \alpha_2\alpha_3\alpha_5 l_{b,rqd,PIR}$ [SS EN 1992-1-1 Eq. 8.4]
  $= 1.0x1.0x1.0x354$
  $= 354mm$

Provide anchorage length of 360mm for bottom PIR 3H13

Summary of design for PIR:

- Provide 3H13 ($A_{s,prov} = 396mm^2 > A_{s,rqd} = 292mm^2$) with $l_{bd,PIR} = 200mm$ for top PIR
- Provide 3H13 ($A_{s,prov} = 396mm^2 > A_{s,min} = 119mm^2$) with $l_{bd,PIR} = 360mm$ for bottom PIR

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Appendix A

Post-Installed Reinforcement According to 2^{nd} Generation Eurocode 2

A.1. INTRODUCTION

The British Standards Institution published the second-generation Eurocode 2 (BS EN 1992-1-1:2023) in 2023, which will soon replace the current Eurocode 2 in the UK. A significant change in the new standard is the inclusion of guidance for PIR, previously absent from the current Eurocode 2. While Singapore is currently reviewing the application of the second-generation Eurocode 2, this Appendix aims to provide insight into the PIR-relevant information from this standard. The content herein is for informational purposes only and not intended for immediate design or application. It should be noted that the rules and details in the second-generation Eurocode 2 or this Appendix are not interchangeable with the guidance provided in the main text of this Guide.

A.2. MINIMUM CONCRETE COVER

The second-generation Eurocode 2 provides guidance on detailing, minimum mean bond strength and design for PIR. Many of these rules align closely with the current provisions in this Guide.

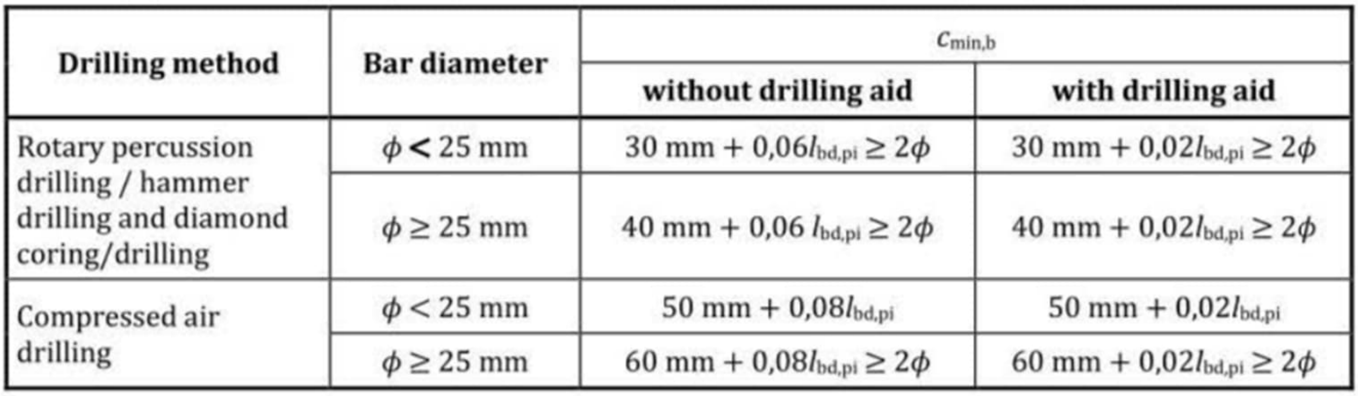
For instance:

(a) The minimum clear spacing between individual PIR in parallel should be 4ϕ or 40mm, whichever is greater.

(b) The minimum clear spacing between PIR and cast-in rebar should not be less than 2ϕ or 20mm, whichever is greater.

Table A.1 presents the minimum concrete cover for PIR, which is similar to Table 4 in the main text of this Guide. The allowance in design for deviation in cover, Δc_{dev}, for PIR is 5 mm or according to project specifications.

Table A.1. Minimum concrete cover $c_{min,b}$ for PIR, adopted from BS EN 1992-1-1:2023

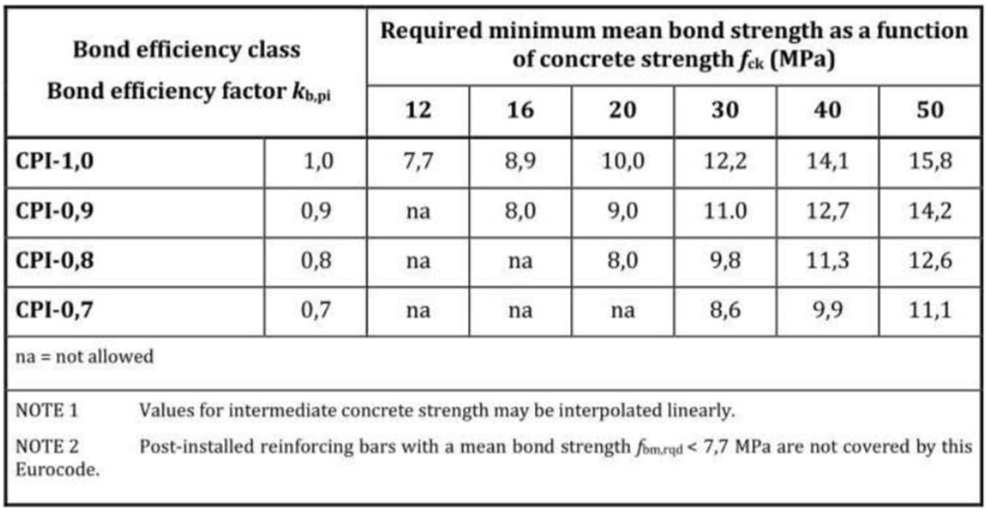


Drilling method	Bar diameter	$c_{min,b}$	
		without drilling aid	with drilling aid
Rotary percussion drilling / hammer drilling and diamond coring/drilling	$\phi < 25$ mm	$30\text{ mm} + 0{,}06 l_{bd,pi} \geq 2\phi$	$30\text{ mm} + 0{,}02 l_{bd,pi} \geq 2\phi$
	$\phi \geq 25$ mm	$40\text{ mm} + 0{,}06\ l_{bd,pi} \geq 2\phi$	$40\text{ mm} + 0{,}02 l_{bd,pi} \geq 2\phi$
Compressed air drilling	$\phi < 25$ mm	$50\text{ mm} + 0{,}08 l_{bd,pi}$	$50\text{ mm} + 0{,}02 l_{bd,pi}$
	$\phi \geq 25$ mm	$60\text{ mm} + 0{,}08 l_{bd,pi} \geq 2\phi$	$60\text{ mm} + 0{,}02 l_{bd,pi} \geq 2\phi$

A.3. MINIMUM MEAN BOND STRENGTH

The minimum mean bond strength requirements in the second-generation Eurocode 2 are similar to those presented in EAD 330087. The bond efficiency factor ($k_{b,pi}$) is product-dependent and can be obtained from the relevant ETA. Table A.2 provides the required minimum mean bond strength.

Table A.2. Required minimum mean bond strength $f_{bm,rqd}$, adopted from BS EN 1992-1-1:2023



Bond efficiency class **Bond efficiency factor $k_{b,pi}$**		**Required minimum mean bond strength as a function of concrete strength f_{ck} (MPa)**					
		12	**16**	**20**	**30**	**40**	**50**
CPI-1,0	1,0	7,7	8,9	10,0	12,2	14,1	15,8
CPI-0,9	0,9	na	8,0	9,0	11.0	12,7	14,2
CPI-0,8	0,8	na	na	8,0	9,8	11,3	12,6
CPI-0,7	0,7	na	na	na	8,6	9,9	11,1
na = not allowed							
NOTE 1 Values for intermediate concrete strength may be interpolated linearly. NOTE 2 Post-installed reinforcing bars with a mean bond strength $f_{bm,rqd}$ < 7,7 MPa are not covered by this Eurocode.							

A.4. DESIGN ANCHORAGE LENGTH

The calculation of design anchorage length in the second-generation Eurocode 2 differs from current provisions. The design anchorage length, l_{bd} (see illustration in Figure A.1), can be calculated as follows:

$$l_{bd} = k_{lb} k_{cp} \emptyset \left(\frac{\sigma_{sd}}{435}\right)^{n\sigma} \left(\frac{25}{f_{ck}}\right)^{\frac{1}{2}} \left(\frac{\emptyset}{20}\right)^{\frac{1}{3}} \left(\frac{1.5\emptyset}{c_d}\right)^{\frac{1}{2}} \geq 10\emptyset \qquad \text{[BS EN 1992-1-1 Eq. 11.3]}$$

where,

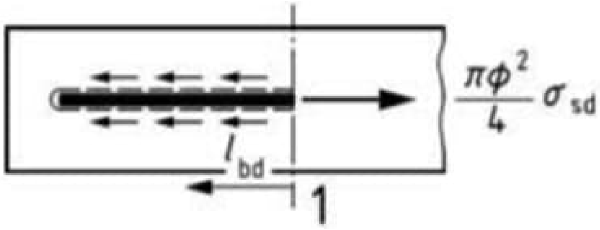
Ratios shall be limited to (ϕ/20mm) ≥ 0.6 and (25/f_{ck}) ≥ 0.3

c_d = min{0.5c_s; c_x; c_y; 3.75ϕ}, see Figure A.2

k_{cp} = coefficient accounting for casting effects on bond conditions, 1.0 (good bond conditions); 1.2 (poor bond conditions); 1.4 (executed under bentonite or similar slurries unless data is available)

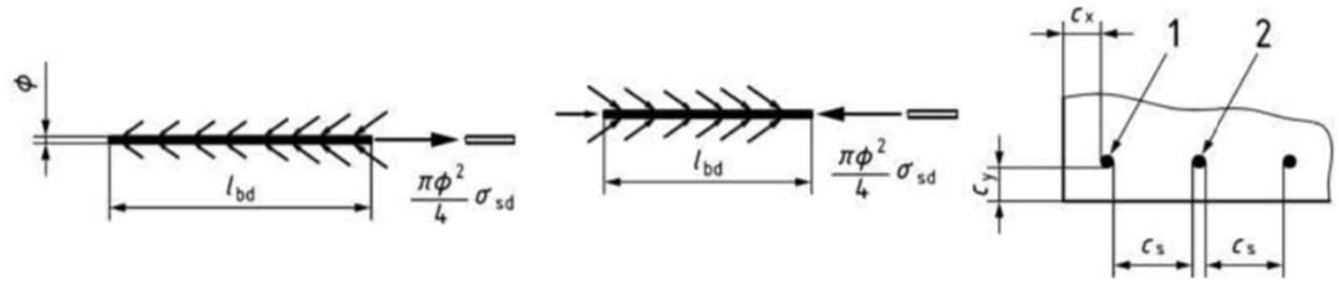
k_{lb} = 50 (persistent and transient design situations); 35 (accidental design situations)

$n\sigma$ = 3/2



1: start of anchorage

Figure A.1. Anchorage of bonded PIR, adopted from BS EN 1992-1-1:2023



a) tension b) compression c) conditions for c_d

Key

1 corner bar

2 edge bar

nominal cover $c_d = \min\{0{,}5c_s; c_x; c_y; 3{,}75\phi\}$

Figure A.2. Definition of design anchorage length for straight bars and c_d, adopted from BS EN 1992-1-1:2023

The second-generation Eurocode 2 provides the design anchorage length of PIR ($l_{bd,pi}$)in both tension and compression, which should be calculated as:

$l_{bd,pi} = \frac{l_{bd}}{k_{b,pi}} \geq 10\emptyset\alpha_{lb}$ [BS EN 1992-1-1 Eq. 11.12]

where,

l_{bd} = calculated according to BS EN 1992-1-1 Eq. 11.3, where the concrete strength shall be limited to $f_{ck} \leq$ 50MPa or the value stated in the European Technical Product Specification (whichever is larger), and the design stress in the rebar be limited to $\sigma_{sd} \leq$ 435MPa unless tested to higher values

$k_{b,pi}$ = bond efficiency factor, see Table A.2

α_{lb} = factor accounting for cracks along the bar which may be taken as 1.5 in general or as given in the European Technical Product Specification

In the case of a lap splicing connection, PIR may be lapped with straight cast-in rebar with design lap lengths, $l_{sd,pi}$. The lap length should be designed for the minimum concrete cover of either cast-in or PIR and the bond conditions of the cast-in rebar.

$l_{sd,pi} = k_{ls} l_{bd,pi} \geq 15\emptyset$ [BS EN 1992-1-1 Table 11.3]

where,

k_{ls} = 1.2 unless National Annexes states otherwise