Guide for Design, Installation, and Assessment of Post-installed Reinforcements

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HKU PRESS
香港大學出版社

Hong Kong University Press
The University of Hong Kong
Pokfulam Road
Hong Kong
https://hkupress.hku.hk

ISBN 978-988-8528-60-8 (*Paperback*)

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library.

10 9 8 7 6 5 4 3 2 1

Printed and bound by Hang Tai Printing Co., Ltd. in Hong Kong, China

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Preface

Post-installed reinforcements use adhesive or cementitious grout to bond the reinforcements and concrete together. They are widely used to connect new structural components to old concrete structures. However, design guidelines for post-installed reinforcements that specifically emphasise material quality and quality control are not available in Hong Kong.

Guide for Design, Installation, and Assessment of Post-installed Reinforcements (hereinafter the Guide) is the first of its kind in Hong Kong and provides a comprehensive summary of the most recent design theories, available adhesion systems, appropriate installation methods, and quality control of post-installed reinforcements. The highlights of the Guide are as follows:

(1) The Code of Practice for Structural Use of Concrete 2013 is applied to the most recent developments in post-installed reinforcement requirements under design frameworks in Europe.
(2) Six proposals are offered to circumvent the issues of long anchorage length, without compromising the structural safety of the connection.
(3) Practical design examples are provided for both simply supported and moment connection cases, including an advanced strut-and-tie method, which has been validated recently through testing carried out at the University of Hong Kong.

The Guide provides good practices for the design, installation, and quality control of post-installed reinforcements. It is a useful reference for designers, contractors, and building control bodies.

Ray K. L. Su
29 February 2020

Abbreviations

ACI	American Concrete Institute
BA	Anchorage design for bonded anchors
BSI	The British Standards Institutions
CEN	European Committee for Standardization
EAD	European Assessment Document (documentation of the methods and criteria accepted in EOTA as being applicable for the assessment of the performance of a construction product in relation to its essential characteristics)
EOTA	European Organisation for Technical Assessment
ETA	European Technical Assessment (a document providing information about the performance of a construction product, to be declared in relation to its essential characteristics)
ETAGs	European Technical Assessment Guidelines (valid to 30 June 2013)
HKBD	Hong Kong Buildings Department
ICC-ES	International Code Council Evaluation Service, Inc.
MPII	Manufacturer's published installation instructions
RC	Reinforced concrete
RA	Anchorage design for reinforcing bar
STM	Strut-and-tie model
ULS	Ultimate limit state

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Introduction of Post-installed Reinforcements

1.1 Scope of guidelines

Conventionally, reinforcements are placed in formwork prior to concrete pouring. These 'pre-installed' reinforcements used in conventional construction methods are known as cast-in reinforcements, which are used to form monolithic construction. However, in many current construction circumstances, reinforcements are post-installed in existing structures with alteration and addition (A&A) work or retrofitting work, or deliberately designed for the convenience of the construction sequence. Post-installed reinforcements are drilled and installed into cured concrete, which are bonded by using a qualified adhesion system on one side of the interface, and usually serve as starter-bars and/or used to create lap splices with the reinforcements in new concrete structures on the other side of the interface. Hence, post-installed reinforcements should not be confused with post-installed anchor bolt systems, as the latter are commonly used to connect concrete with steel structural or non-structural elements (i.e., concrete pedestals and steel column base plates or reinforced concrete (RC) slabs and handrails). The Guide provides the installation, design, and assessment guidelines for post-installed reinforcements. Readers are advised to refer to a local Hong Kong reference for post-installed anchor bolt systems (Cho and Chan, n.d.).

Some application examples of post-installed reinforcements are shown in Figure 1.1. New RC slabs or beams can be attached horizontally with post-installed reinforcements onto existing RC shear walls and columns (see Figure 1.1(a) on p. 2) or slabs (see Figure 1.1(b)). Figure 1.1(c) shows an example of an RC column that is cast vertically into a foundation with or without lap splices. New concrete can be overlaid for wall strengthening, column jacketing, and slab thickening by using post-installed reinforcement technology (see Figure 1.1(d)).

1.1.1 International guidelines for post-installed reinforcements

Despite the popular use of holistic design principles and practices in construction, those for post-installed reinforcement systems are not explicitly provided in modern international structural design codes (for example, EN 1992-1-1 (2004) and ACI 318 (2014)). However, the rationality of some of the design philosophies can be traced in codes based on the associated failure modes; for instance, the provisions for anchorage length design (i.e., Cl. 8.4 in EN 1992-1-1 (2004) and Chapter 25 of ACI 318

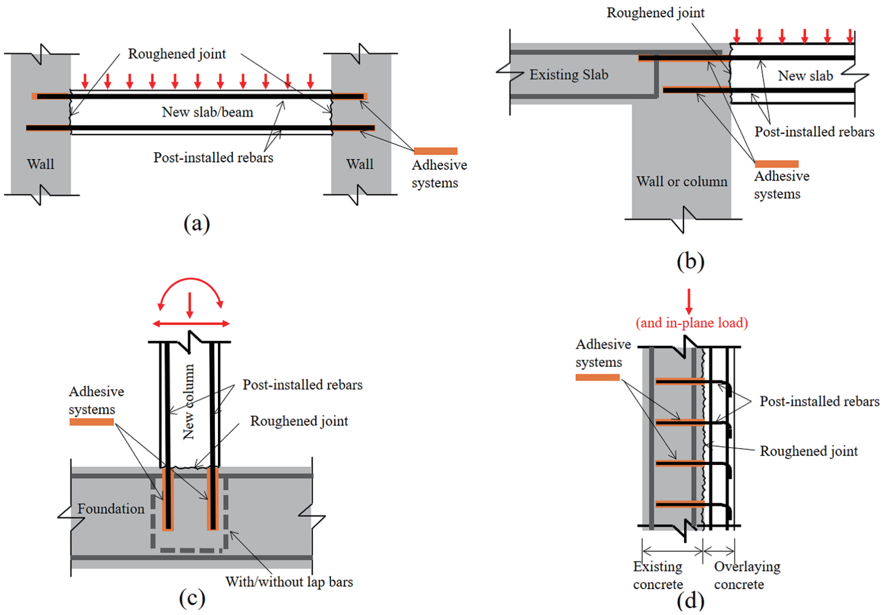

Figure 1.1: Typical application examples of post-installed reinforcements: (a) end anchor of new slab/beam attached onto walls (shear or diaphragm wall); (b) lap splice of new slab attached to existing slab; (c) end anchor with/without lap splice as moment resisting connection; and (d) new concrete overlays (e.g., for wall strengthening, column jacketing, and slab thickening) (note: no transverse reinforcement is used)

(2014)) and lap splicing length (i.e., Cl. 8.7 in EN 1992-1-1 (2004) and Chapter 25 of ACI 318 (2014)). On the contrary, the anchor procedure is provided in EN 1992-4 (2018) and Chapter 17 of ACI 318 (2014). More detailed discussions can be found in Charney et al. (2013) and Morgan (2015).

The load-slip performance of post-installed reinforcements under static loading installed by using a qualified system can be similar or exceed that of a cast-in reinforcement according to extensive research carried out by Spieth (2002), whilst Simons (2007) investigated the seismic behaviour. Thus, the design provisions of end anchorages for cast-in reinforcements can be extended to post-installed reinforcements along with qualified products. Specific guidelines have been produced that qualify post-installed reinforcements designed by using the reinforcement anchorage (RA) design procedure, for example, EAD 330087-00-0601 (2018) (which replaces the TR 023 (2006) published by the European Organisation for Technical Assessment (EOTA)) and the AC 308 (2016) in Europe and the United States (US), respectively. On the contrary, post-installed reinforcements that meet guidelines such as EAD 330499-00-0601 (2017) and AC 308 (2016) in Europe and the US, respectively, can be designed based on the bonded anchor (BA) design procedure. Table 1.1 is a summarised list of the most relevant international documents and their requirements in using post-installed reinforcements (with relevant documents on post-installed anchors), for ease of reference and to facilitate the discussions hereafter. Note that this document does not consider other standards (e.g., EN 1504-6:2006) that allow products to be certified by following different requirements, that do not address the most critical installation conditions, and are not tied to available design building codes.

Table 1.1: List of international documents for qualification and design of post-installed reinforcements

Document	Organisation	Role and function	Remarks
Qualification			
EAD 330087-00-0601 (2018)	EOTA	Qualification of post-installed reinforcements in Europe under static loading and fire exposure.	Replaces TR 023 (2006). Design in accordance with EN 1992-1-1 and 1992-1-2 (2004).
EAD 331522-00-0601-00-0601 (endorsed draft 2018)	EOTA	Qualification of post-installed rebars with mortar under seismic conditions.	Listed on EOTA website; pending publication in the Official Journal of the European Union* Design in accordance with EN 1992-1 (2004).
AC 308 (2016)	International Code Council Evaluation Service, Inc. (ICC-ES)	Qualification of post-installed reinforcements and adhesion anchors under static and seismic loading.	Use with test criterion to supplement ACI 355-4 (2011). Design in accordance with Ch. 25 of ACI 318 (2014)
ACI 355.4 (2011)	ACI	Qualification of post-installed adhesion anchors under static and seismic loading.	Design in accordance with Ch. 17 of ACI 318 (2014).
EAD 330499-00-0601 (2017)	EOTA	Qualification of post-installed anchors under static loading in Europe.	Design in accordance with EN 1992-4 (2018) or CEN/TS 1992-4-5 (2009)
EOTA TR 049 (2016)	EOTA	Qualification of post-installed anchors under seismic loading in Europe.	Design in accordance with EN 1992-4 (2018) or EOTA TR 045 (2013)
Design			
EN 1992-1-1 (2004)	CEN	General reinforced concrete design in Europe.	Design provisions for anchorage and splice length in Chapter 8.

Table 1.1: Cont'd

Document	Organisation	Role and function	Remarks
ACI 318 (2014)	ACI	General reinforced concrete design in the US.	Design provisions for development length (rebar design procedures) in Chapter 25, and anchor design procedures in Chapter 17.
EOTA TR 045 (2013)	EOTA	Guidelines for design of post-installed anchors in Europe.	Superseded by EN 1992-4 (2018)
EN 1992-4 (2018)	CEN	Standard for design of post-installed anchors in Europe.	
BS 8539 (2012)	BSI	Selection and installation of post-installed anchors in the UK.	Recommendations for anchors without European Technical Approval (ETA) qualification.

Note: * The first citation of EADs needs to be in the Official Journal of the European Union and subsequent to publication, and available for download on the European Commission website.

1.1.2 Relevance to the local Hong Kong design guide

In Hong Kong, the Buildings Department (BD) of the Hong Kong government recommends the use of the Code of Practice for Structural Use of Concrete 2013 (hereinafter HKBD 2013) for designing, constructing, and controlling the quality of RC buildings and structures where the concrete is made with normal weight aggregates. HKBD 2013 was drafted with substantial reference to the now defunct British standard BS 8110 Part 1 1997 (superseded by EN 1992-1-1:2004). The minimum end anchorage bond length requirement is similar in the two codes, where yield strength of the reinforcement is assumed. The clauses are Cl. 8.4 in HKBD 2013 and Cl. 3.12.8.3 in BS 8110 (1997). There are no specific calculations required for the lap length in HKBD 2013, but provisions are given based on some deemed-to-comply practices, commonly for the length of bars of different sizes. Compared to the requirements in EN 1992-1-1 (2004) (i.e., anchorage length in Cl. 8.4.4 and splicing length in Cl. 8.7.3) or the splicing development length formula in Cl. 25.4.2.3 of ACI 318 (2014), the anchorage or splice length design in HKBD 2013 has not accounted for different variables such as the shape/size of the bars, concrete minimum cover, confinement effects, casting position, and type of grout or epoxy used.

A review of the relevant clauses in HKBD 2013 showed that this code might not be directly applicable to post-installed reinforcements for the following reasons:

(1) Adhesion systems are not codified in the local codes of practice. The Hong Kong Building Authority has provided guidelines for approving post-installed anchors, but not post-installed reinforcements. Cementitious/polymer-based grout

dowels/reinforcing bars can be provisionally approved in construction based on a BD approval letter.

(2) The approach for reinforcement detailing at the joints in the local codes of practice often requires a long anchorage length, which makes post-installed reinforcements impractical, as bending of the bars is not possible. This is due to the conservative assumption that the design stress of the reinforcement reaches its yield strength.

Similar challenges are found with the use of generic RC design codes such as EN 1992-1-1 (2004) and ACI 318 (2014). Hence, the publication of the EAD 330087-00-0601 (2018) (which supersedes TR 023 (2006)), and AC 308 (2016) by the EOTA in Europe and the American Concrete Institute (ACI) in the US, respectively, is to qualify the use of post-installed reinforcements in concrete structures. Therefore, guidelines for post-installed reinforcements that refer to the latest technologies and correspond with HKBD 2013 are necessary for local practices in Hong Kong.

The aim of the Guide is to establish guidelines for installing, designing and assessing post-installed reinforcements that are subjected to mainly static loads (with an introduction on exposure to fire and seismic conditions) by referring to HKBD 2013, EN 1992-1-1 (2004), ACI 318 (2014), EN 1992-4 (2018), EAD 330087-00-0601 (2018), EAD 331522-00-0601 (endorsed draft 2018) and AC 308 (2016).

The Guide is to be used in conjunction with HKBD 2013 or other relevant design codes to design other RC elements or inspect existing structural elements that are not included in the Guide.

1.2 Post-installed and cast-in reinforcements

This section provides an introduction on several concepts that have importance to the readers of the Guide for differentiating the behaviour (including load transfer and failure process) between post-installed and cast-in reinforcements.

1.2.1 Local load transfer mechanism among reinforcements, bonding agent, and concrete

The bond strength of reinforcements is important for effectively transferring load to the surrounding concrete. It is commonly assumed for design purposes (uniform-bond model) that the distribution of the average bond stress along the embedded length of the reinforcement is constant for both cast-in and post-installed reinforcements.

The bond force is the force that moves a reinforcing bar along the length of its longitudinal axis with respect to the surrounding concrete. The bond strength is the maximum bond stress that can be sustained by a bar in concrete (ACI 408R, 2003). Figure 1.2 schematically shows the load transfer mechanism of cast-in and post-installed reinforcements under tension. In Figure 1.2(a), which shows the cast-in reinforcement, the load is mainly transferred by the mechanical interlocking of the ribs at the reinforcement-concrete interface. The reaction forces within the concrete are assumed to be in the form of compressive struts, which are inclined to the axis of the reinforcement. The vector bearing forces can be decomposed in the parallel and perpendicular directions to the longitudinal axis of the reinforcement. The sum of the

4
Design Methods and Examples

Different design methodologies have been developed in Europe and the US which allow for the use of post-installed reinforcing bars. This chapter discusses the available design methods and proposes a rational option for post-installed reinforcements in accordance with HKBD 2013. Written with substantial reference to the now defunct BS 8110 Part 1 1997, HKBD 2013 is compatible with the Eurocodes rather than the US codes. Hence, the European approach (i.e., the (i) RA design procedure: prequalification with EAD 330087-00-0601 (2018) then designed in accordance with EN 1992-1-1 (2004), and the (ii) BA design procedure: prequalification with EAD 330499-00-0601 (2017) then designed in accordance with EN 1992-4 (2018)) will be used as the background documents that provide a local design method accommodating the context of Hong Kong. Readers of the Guide are encouraged to refer to fib Bulletin 58 (fédération internationale du béton, 2011a) for additional reading material.

4.1 Identifying key design parameters

The design of post-installed reinforcing bar connections requires the engineer to determine the type of reinforcement, size, spacing, anchorage, and splice lengths of the reinforcement, as well as the quantity of reinforcements. The key parameters of the existing structure, site constraints, and arrangements of the connections which would affect the connection design are summarised in Table 4.1 on p. 31.

4.2 Design philosophy for post-installed reinforcements: Reinforcement and bonded anchors

4.2.1 Comparison of current provisions for post-installed reinforcement designs: European standards

The international documents listed in Table 1.1 are used to facilitate the discussion in this section. In general, post-installed reinforcements can be rationally designed based on the RA or BA design procedures, with differences in assumptions and being subjected to limitations. For the prequalification of post-installed reinforcements that use the RA design procedures, EAD 330087-00-0601 (2018) is used to determine the suitability of the adhesion system for post-installed reinforcements. After an adhesion

Table 4.1: Factors affecting post-installed rebar connection designs

Pre-qualification	(1) Adhesive assessment standard Rebar anchorage design procedures: EAD 330087-00-0601 (2018) or bonded anchor design procedures: EAD 330499-00-0601-00-0601 (2017)
Base materials and reinforcement	(1) Strength grade of concrete (2) Condition of concrete (cracked or uncracked, carbonated or non-carbonated, etc.) (3) Maximum chloride content in concrete (4) Ultimate bond strength and design bond strength of adhesive (5) Minimum thickness of base material (6) Yielding strength of reinforcement
Jobsite constraints	(1) The minimum and maximum concrete temperatures at time of installation and during the entire design life (2) Access and geometrical constraints on jobsite
Installation	(1) Requirements for preparation/roughening of existing concrete surface (2) Requirements for hole drilling (hammer, core, or compressed air drill) (3) Hole diameter (4) Orientation of connection (downward, horizontal, or overhead) (5) Environmental condition of concrete (dry, water-saturated, water filled, or flooded) (6) Existing reinforcement layout and size as given in drawing and confirmed on site with detection equipment (7) Requirements for training/certification of installers and supervisor
Design requirements	(1) Design code (rebar anchorage design procedures: EN 1992-1-1 (2004) and HKBD 2013 or bonded anchor design procedures: EN 1992-4 (2018) (2) Design life (3) Load type (sustained, static, quasi-static, seismic, shock, and wind) (4) Fire requirements (5) Corrosion resistance (6) Creep (7) Fatigue (8) Seismic

system has been suitably qualified, post-installed reinforcements can be designed using the RA design procedures based on Chapter 8 in EN 1992-1-1 (2004).

On the contrary, EAD 330499-00-0601 (2017) (formerly Part 5 of ETAG 001, 2013) provides provisions to determine the suitability of mortars or adhesives used for the anchor in the prequalification of bonded anchors. After an adhesion system has been suitably qualified, the anchor can then be designed in accordance with EN 1992-4 (2018). Table 4.2a provides a general comparison of both design methods.

Table 4.2a: Comparison of rebar anchorage and bonded anchor design procedures, using most relevant European standards

Main difference	Rebar anchorage design procedures	Bonded anchor design procedures
Adhesive assessment qualification documents	Under static conditions and fire exposure: EAD 330087-00-0601 (2018) Seismic conditions: EAD 331522-00-0601 (endorsed draft 2018)	Under static conditions: EAD 330499-00-0601 (2017) Under seismic conditions: TR 045 (2013)
Design standard	Under static conditions: Chapter 8 in EN 1992-1-1 (2004) Under seismic conditions: Chapter 5.6 in EN 1998-1 (2004)	EN 1992-4 (2018)
Load direction	Tension	Tension, shear, combination of both
Load transfer mechanism	Equilibrium with local or global concrete struts, may require the supplement of transverse reinforcement in lapping splices	Utilisation of tensile concrete strength
Failure mode	<u>Tension</u>: steel failure, pull-out, splitting (near the edge)	<u>Tension</u>: steel failure, cone-shaped concrete breakout (cone failure), bond failure (pull-out), splitting (near the edge) <u>Shear</u>: steel failure, cone-shaped concrete breakout, concrete pryout
Provision to base material	Uncracked concrete*	Cracked and uncracked concrete
Partial safety factor	$\gamma_s = 1.15$**	$\gamma_s = 1.2\ (f_{uk}/f_{yk}) \geq 1.4$** (tension loading)
Basic design value of rebar	Yield strength of rebar	Ultimate strength for anchor and yield strength for rebar

Table 4.2a: Cont'd

Main difference	Rebar anchorage design procedures	Bonded anchor design procedures
Basic design value of bond strength	Deduced by calculation (associated with concrete tensile strength)	Tested and approved (associated with bond strength)
Design steps	a) Calculation of required steel cross-section of reinforcement b) Calculation of required embedment length	a) Calculation of all characteristic capacities b) Determination of minimum capacity that controls failure anchorage
Design results	Reinforcement length	Strength capacity
Allowable embedment length (l_b)	max {0.3 $l_{b,rqd}$; 10 ϕ; 100 mm} $\leq l_b \leq 60\ \phi$ (ϕ is the rebar diameter)	$6\ \phi \leq l_b \leq 20\ \phi$ (ϕ is the rebar diameter)

* The equivalence in terms of pull-out resistance in cracked concrete between a post-installed rebar system and a cast-in bar is checked in the qualification, as per EAD 330087-00-0601 (2018).

** For convenience of comparison with the local practice in Hong Kong, Table 4.2b provides more details on the partial safety factors for both the rebar anchorage and bonded anchor design procedures.

Table 4.2b: Comparison of partial safety factors for rebar anchorage and bonded anchor design procedures, as per European standards and Hong Kong standards and practices

Design procedures	Rebar anchorage	Bonded anchor	
Design standards/ practices	HKBD 2013 (at ULS)	EN 1992-4 (2018) (at ULS)	HK practice (global factor of safety)
Failure mode			
Steel	1.15	(a) $1.2\ (f_{uk}/f_{yk}) \geq 1.4$ (tension loading) (b) $1.0\ (f_{uk}/f_{yk}) \geq 1.25$ (shear loading, for $f_{uk} \leq 800$ N/mm^2 and $f_{uk}/f_{yk} \leq 0.8$) (c) $= 1.5$ (shear loading, for $f_{uk} > 800$ N/mm^2 and $f_{uk}/f_{yk} > 0.8$)	3.0
Concrete cone	N/A	≥ 1.5	3.0
Concrete edge (splitting)	N/A	≥ 1.5	3.0

5 Qualification and Quality Control of Post-installed Reinforcement Connections

The performance of post-installed reinforcement systems is greatly affected by the type of adhesive used (see Chapter 2), drilling and installation methods (Chapter 3), and the designed length and diameter of the holes (Chapter 4). Hence, product qualification procedures should be in place to ensure that the performance of post-installed reinforcement connections is comparable to that of monolithic cast in-situ connections.

As shown in Tables 1.1 and 4.2a, the two main sources of reference for qualifications are the EAD 330087-00-0601 (2018) developed by the EOTA in Europe and AC 308 (2016) by the ACI in the US. This chapter discusses the overall requirements of these two documents in terms of tests and assessment procedures. The differences between the two documents and their commonalities are also identified and elaborated.

5.1 Qualification of system for post-installed reinforcements

5.1.1 Basic principles

In the EAD 330087-00-0601 (2018) and AC 308 (2016), the primary goal of qualification under static conditions is to establish a comparable performance of cast-in reinforcements with respect to the failure modes. Anticipated failure modes (i.e., bond and splitting) have been discussed in Chapter 4 (see Figures 4.5 and 4.8). The comparison in terms of the load-displacement behaviour (i.e., stiffness) is largely based on extensive research work carried out by Spieth (2002).

The basic tension test procedure to derive the average bond strength of a post-installed reinforcement system under various conditions (i.e., dry or wet conditions; different temperatures, directions, and depths; or in corrosive, alkaline, or sulphuric environments) are described in EAD 330087-00-0601 (2018) and AC 308 (2016). Readers are encouraged to refer to these two sources for details.

5.1.2 Applications of EAD 330087-00-0601 (2018) and AC 308 (2016)

Table 5.1 provides a general comparison of the relevant applications of post-installed reinforcing bars (Genesio et al., 2017a). Post-installed reinforcement systems subjected to static conditions are commonly outlined in both the EAD 330087-00-0601 (2018) and AC 308 (2016). The former provides optional testing provisions to assess the exposure of the product to fire whilst the latter provides qualification for seismic conditions. Both have not offered qualification under fatigue conditions. Interestingly, the concrete cover in the EAD 330087-00-0601 (2018) is required to be larger than the cast-in reinforcement design, whereas AC 308 (2016) allows the same cover thickness provided, of which has been validated through testing.

Table 5.1: General comparison of relevant applications of EAD 330087 (2018) and AC 308 (2016)

Condition	EAD 330087-00-0601 (2018)	AC308 (2016)
Under static conditions	YES	YES
Under seismic conditions	Refer to EAD 331522-00-0601 (endorsed draft 2018)	YES
Under fatigue conditions	NO	NO
Exposure to fire	YES	NO
Concrete cover controls	Larger cover than cast-in rebar design in EN 1992-1-1 (2004)	If verified by test, same cover as cast-in rebars in accordance with ACI 318 (2014)

5.1.3 Specific differences between EAD 330087-00-0601 (2018) and AC 308 (2016)

Despite that EAD 330087-00-0601 (2018) and AC 308 (2016) were both largely developed based on the same research findings, they have significant differences. Table 5.2 lists the specific differences between the two documents.

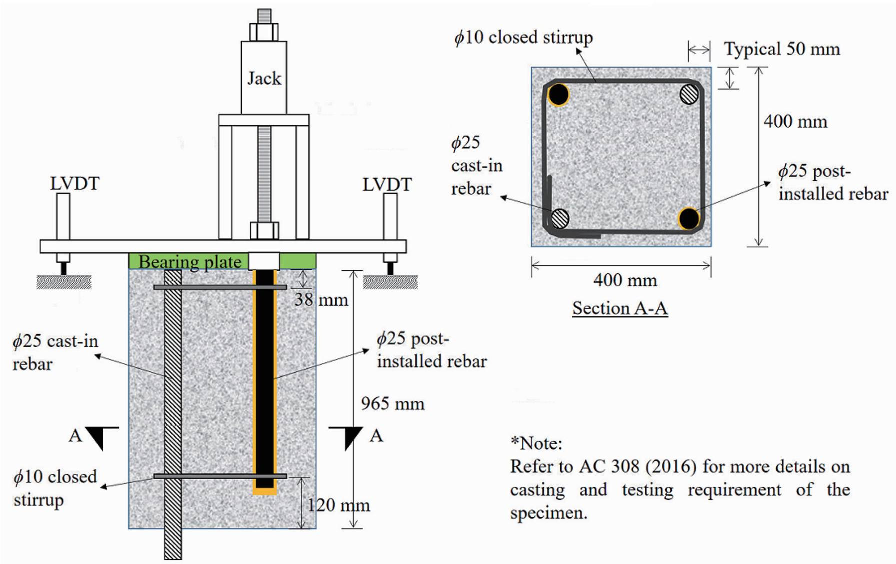

Figure 5.1: Example of splitting test setup, as per AC 308 (2016)

Table 5.2: Specific differences between EAD 330087-00-0601 (2018) and AC 308 (2016)

Test assessment	**EAD 330087-00-0601 (2018)**	**AC 308 (2016)**
Adhesive bond strength	Limit in accordance with $f_{bm}{}^{req} = \frac{\gamma_c f_{bd}}{0.75}\left(\frac{40}{10}\right)^{0.55}$ for concrete class up to C50/60, where f_{bm} is the required bond resistance of post-installed systems, γ_c is the material partial factor for concrete equal to 1.5, and f_{bd} is the design value of ultimate bond resistance in accordance with EN 1992-1-1 (2004) for good bond conditions. If the product exhibits lower average bond strength but has at least f_{bm} = 7.1 MPa, concession is allowed for qualification, with a bond strength reduction factor.	No concession. All limits must be equal or exceed 7.5 MPa and 11.8 MPa for low and high strength uncracked concrete, respectively.
Splitting failure test	None.	Additional test required for bond/splitting behaviour. This is to avoid 'zipper' failure from excessive adhesive stiffness due to shear lag at the corner or near-edge bars. On the contrary, avoid overly 'soft' adhesives, which lead to relaxation, low stiffness, cracks, and corrosion (see Fig. 5.1 for example of test setup).
Cracked concrete test	Optional. Mainly to avoid using long development lengths. Bond strength is reduced by approximately 25% observed in 0.3 mm longitudinal cracks for cast-in bars (Eibl et al., 1997). Performance of post-installed rebars in cracked concrete is assumed to be 50% of uncracked concrete.	Checking the bond strength and displacement is mandatory. Bond strength is reduced by approximately 50% observed in 0.4 mm cracks (Simons, 2007). No assumption of preliminary reduction is made on the performance of post-installed systems.
Minimum edge distance and concrete cover	Minimum edge distance and concrete cover are required, depending on drilling method, bar diameter, and use of drilling aid (see Table 4.5).	Same concrete cover as that for cast-in rebar design in ACI 318 (2014).
Installation depth	To be tested at a reachable depth (e.g., 20 ϕ, 80 ϕ, etc.), which allows for more flexibility and product differentiation.	Requires successful installation at a depth of 60 ϕ.

5.1.4 Seismic assessments: Cyclic testing as per EAD 331522-00-0601 (endorsed draft 2018) and AC 308 (2016)

The probability of a large earthquake occurring in Hong Kong is low due to its geographical location. Whilst Hong Kong is not located anywhere near a tectonic boundary, the city is however subjected to low-to-moderate intraplate seismic activity. Therefore, there has been effort made to draft seismic design codes (HKBD, 2017). This section will present the assessment methods for post-installed reinforcements subjected to seismic loads in the EAD 331522-00-0601 (endorsed draft 2018) and AC 308 (2016). Engineers are reminded to first qualify the post-installed reinforcement system under static loading as a pre-requisite before proceeding to conducting a seismic assessment.

EAD 331522-00-0601 (endorsed draft 2018)

The EAD 331522-00-0601 (endorsed draft 2018) provides a detailed method for the seismic assessment of post-installed reinforcement systems by taking both small and large covers into consideration. Seismic bond splitting tests are used for small covers to check that the dissipated energy of a post-installed reinforcement is not lower than that of a cast-in bar. More specifically, if a post-installed reinforcement system does not fulfil this criterion, installation can only proceed with a larger minimum concrete cover that is comparable to the bond strength in case there is seismic loading. This provision applies across other standards and should be used jointly with EN 1992-1-1 (2004) and EN 1998-1 (2004), taking into account the reduction factor (k_b) in Section 2.2.2 and amplification factor for minimum anchorage length (α_{lb}) in Section 2.2.3 of EAD 330087-00-0601 (2018).

The test setup to determine the bond strength under seismic loading is shown in Figure 5.2. The drilled hole should be deep enough to prevent the reinforcement from coming into contact with the end of the hole. A compressible material should be inserted at the bottom of the hole prior to injecting the adhesive and inserting the bar. This confinement test is conducted with a friction reducing material placed between the confining plate and the concrete surface. The objective of the test is to check whether there are any increases in the bond-strength degradation of post-installed reinforcements with increasing numbers of cycles versus cast-in reinforcements. The bond strength for seismic applications ($f_{bd,seis}$) is intended to replace the bond strength for static loading (f_{bd}) in EN 1992-1-1 (2004). The required bond stress under cyclic activity is summarised in the EAD 331522-00-0601 (endorsed draft 2018).

AC 308 (2016)

The testing equipment and specimens used to obtain the seismic resistance of post-installed reinforcements under seismic conditions based on AC 308 (2016) are shown in Figure 5.2 (see p. 82). The setup is similar to that based on the EAD 331522-00-0601 (endorsed draft 2018). Note that splitting failure under cyclic loading is required with the EAD 331522-00-0601 (endorsed draft 2018). The required bond stress under cyclic activity is summarised in AC 308 (2016). Readers are encouraged to refer to these two documents for details.

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