Non-seismic and seismic qualification and design of anchor channels with channel bolts

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Abstract

Anchor channels cast in reinforced concrete members allow easy adjustable connection of components to reinforced concrete structures using twisted-in channel bolts. Connections with anchor channel-channel bolt systems are very robust and suitable to cope with earthquake loads. For these reasons, anchor channels with channel bolts are popular for non-seismic as well as for seismic applications in particular for industrial and infrastructure projects.

For safety relevant connections, anchor channels and channel bolts have to be adequately qualified and carefully designed. While the qualification and design of post-installed and cast-in concrete anchors was recently completely codified, the code framework for anchor channels is still in development.

This paper explains the basics of anchor channel-channel bolt applications and the engineering of the same. Furthermore, the currently relevant codes for qualification and design of anchor channel-channel bolt systems in the USA and Europe are briefly introduced to guide specifiers and engineers.

Keywords: anchor channel, channel bolt, earthquake engineering, qualification, design, reinforced concrete

1. Introduction

Since their invention by Jordahl in 1913, anchor channels with channel bolts (aka T-bolts) provide versatile possibilities to connect components, e.g. façade elements, elevator railings, MEP works, platforms and ladders to reinforced concrete structures (Figure 1). According to modern building design codes, concrete anchors have to be approved by independent bodies if used for safety relevant connections. Because of their high load capacity, anchor channels with channel bolts are used to fix heavy loads and therefore in general require qualification. Beside the careful selection of a suitable and qualified products by the specifier, a professional structural design of anchor channel and channel bolt is required for a safe connection.

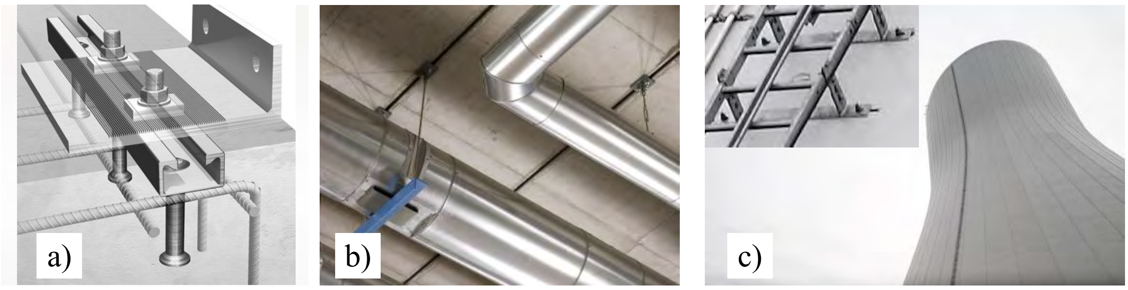

Figure 1. Anchor channels and channel bolts for the connection of a) façade elements, b) MEP works and c) ladders of power plants.

The qualification and design is particularly important if anchor channels and channel bolts are used for seismic applications. Otherwise, adequate seismic performance of the anchor channel-channel bolt system may be inhibited and failures during earthquakes may occur. E.g. in nuclear power plants, failure of connections may have hazardous consequences, endangering health and causing substantial economic loss due to disruptions.

Getting a full picture of available qualification guidelines and applicable design rules is challenging – also because the code framework for qualification and design of anchor channel-channel bolt systems is not yet fully completed. For this reason, product specifiers and structural engineers may be confused and misguided.

The goal of this paper is to provide the background and an overview of qualification and design codes for anchor channels with channel bolts. To this end, the regulations currently to be taken into account in the *USA* and *Europe* are introduced. Note that some countries, e.g. *Australia*, adopt the European regulations with regard to concrete anchors, while others, e.g. *New Zealand* rather follow the regulations of the USA.

2. Background of anchor channels

The development of anchor channels more than 100 years ago was driven by the need to connect transmission belts to ceilings made of the then upcoming reinforced concrete structures (Figure 2a). T-shaped channel bolts are locked into C-shaped channels which are fitted with anchors (Figure 2b) and cast flush in reinforced concrete. Conventional anchor channels allow the transfer of tension loads (N) and shear loads perpendicular to the channel (V_y). To enable the load transfer also in the direction of the channel (V_x), serrated anchor channels and matching serrated channel bolts were developed in the 1980s, making the transfer in all direction of the channel possible (Figure 2c). Simulated seismic load tests showed that the load bearing behaviour of the serrated connection is very robust because adjacent teeth are activated after failure of the teeth in the contact area between the head of the channel bolt and the lips of the anchor channel (Park and Plamper-Hellwig (2012)).

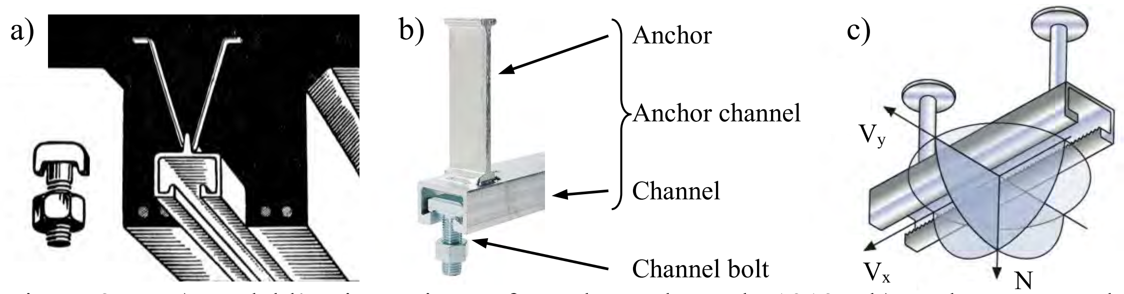

Figure 2. a) Jordahl's invention of anchor channel 1913, b) anchor channel components and channel bolt, c) state-of-the art systems allow load transfer in all directions.

For installation, the anchor channel is glued or nailed to the formwork (Figure 3a). Anchor channels are generally furnished with filler material to prevent that concrete slurry is leaking into the profile during concreting. After the concrete is set and the formwork is stripped off, the filler is removed (Figure 3b and c). Channel bolts inserted and twisted in the slot of the channel then allow fastening of components at any point along its length (Figure 3d).

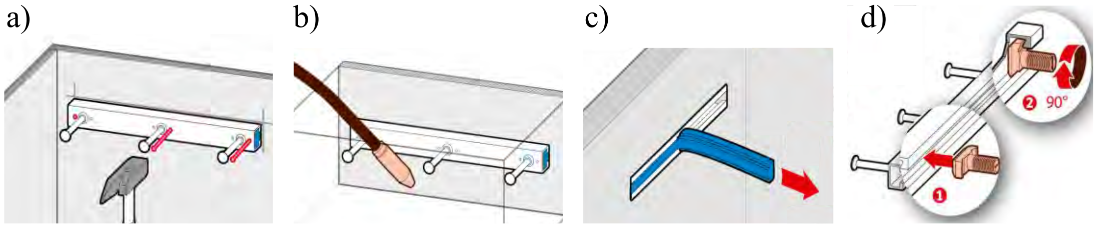

Figure 3. Installation sequence a) attaching of anchor channel to formwork, b) casting of concrete, c) removing of filler, d) twisting-in of channel bolt.

Anchor channels with channel bolts have several benefits:

- Compensation of building tolerances by adjustable bolt fit during installation
- Robust load transfer due to mechanical interlock (bolt-channel, anchor-concrete)
- No on-site welding required as for anchor plates, thus no quality issues
- No on-site drilling required as for post-installed anchors, thus no cut reinforcement
- Quick, easy and fool-proof installation of anchor channel during construction
- Connecting, disconnecting and sliding of attachment using channel bolt during complete life cycle of building

3. Qualification and design of anchor channels

In modern buildings, numerous connections to concrete are required to anchor mostly non-structural but also structural components. Concrete anchors are primarily post-installed anchors or cast-in anchor channels with channel bolts. During the past century, very different concrete anchors with increasing load capacities were developed. Previously, the design of concrete anchors mainly relied on qualification tests carried out and reported by the manufacturers. Design data provided in standardised qualification certificates published by construction authorities became mandatory for concrete anchor applications in some countries in the 1970s. After several collapses of connections with concrete anchors, e.g. the support of a safety related piping system in a Nuclear Power Plant in 1979, more attention was paid to concrete anchor design and extended research was carried out.

Research on anchor channels with channel bolts was intensified during the last two decades and included studies to determine the behaviour of anchor channel-channel bolt systems when installed in thin members and with supplementary reinforcement (Oluokun and Burdette (1993); Wohlfahrt (1996)). After the development of substantiated design equations for non-seismic loads (Kraus (2002); Potthoff (2008)), the influence of seismic loads (Güreş (2005); Butenweg and Park (2011)) was investigated in detail.

Design equations are used to verify the strengths corresponding to various failure modes. While most *one-dimensional* post-installed and cast-in anchors fail either by steel (mode S), concrete breakout (mode C), or pullout (mode P), *two-dimensional* anchor channels-channel bolt-systems may develop 18 different failure modes if loaded in tension and shear (Figure 4). The capacity of the connection is governed by the lowest strength of all possible failure modes. For verification during the structural design, the capacity is therefore determined by the minimum result from all design equations corresponding to the individual failure modes. Simultaneous acting tension and shear loads, i.e. inclined loads, are taken into account by an interaction formula. The design equations allow a rather conservative estimation of the capacity because of the limited accuracy of the underlying models representing the complex failure modes of anchor channel-channel bolt systems.

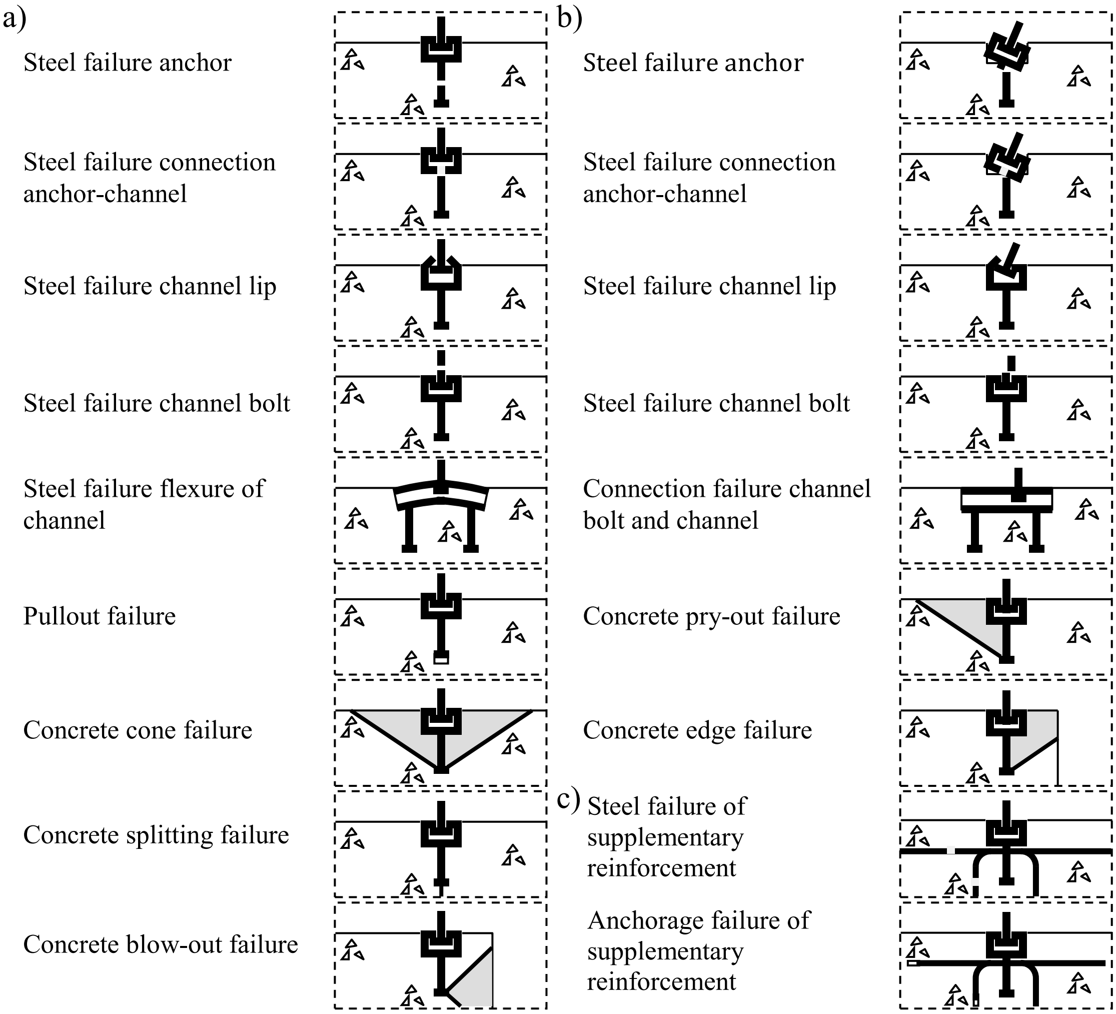

Figure 4. Verifications for anchor channels and channel bolts loaded in a) tension b) shear and c) tension or shear.

The qualification and design of products for anchoring in concrete in the *USA* and *Europe* have been streamlined over the years. For this reason, crosswise recognition of qualification tests and assessments became possible and design concepts basically identical. The most important background of the qualification and design documents for non-seismic and seismic applications in the USA and Europe is explained in the following. Table 1 provides an overview of the current qualification and design documents applicable for anchor channel-channel bolt systems.

Table 1. Current qualification and design documents in the USA and Europe for anchor channels with channel bolts used for non-seismic and seismic applications.

	Application	USA	Europe
Qualification	Non-seismic	AC232	EAD 330008-02-0601
	Seismic		–
Qualification Document with Design Data		E(S)R	ETA
Design	Non-seismic	ACI 318, AC232	EN 1992-4, CEN/TR X
	Seismic		–

3.1 Qualification of anchor channels with channel bolts

In the *USA*, *non-seismic* qualification of concrete anchors according to ACI 355 (ACI 355.2 (2007); ACI 355.4 (2011)) does not yet include anchor channel-channel bolt systems. Here, the only available qualification document are the Acceptance Criteria (AC)232 (AC232 (2016)) published by the Evaluation Service of the International Code Council (ICC-ES). *Seismic* qualification of post-installed and cast-in anchors is included in ACI 355 for long and also AC232 has been amended to allow the use of anchor channels with channel bolts for Seismic Design Category (SDC) C to F. Note that SDC A and B does not require a seismic qualification. Qualification is documented by Evaluation (Service) Reports (E(S)R) issued by independent test laboratories, e.g. IAPMO (e.g. ER 0293 (2016)) and ICC-ES (e.g. ESR-2854 (2016)).

Post-installed and cast-in anchors in *Europe* were qualified for *non-seismic* applications according to European Technical Approval Guideline (ETAG) 001 (ETAG 001 (2013)), supplemented with Common Understanding of Assessment Procedure (CUAP) 06.01/01 (CUAP 06.01/01 (2010)) for anchor channels with channel bolts. Currently, the ETAGs and CUAPs are converted into European Assessment Documents (EAD). The EAD 330008-02-0601 for anchor channel-channel bolt systems (EAD 330008-02-0601 (2016)) has been recently published by the European Organisation for Technical Assessments (EOTA). In Europe, qualification of post-installed and cast-in anchors for *seismic* applications is possible since ETAG 001 was amended in 2015 by Annex E. At this point of time, however, no equivalent qualification document was available for anchor channel-channel bolt systems. The qualification results, i.e. the suitability of a tested product for certain applications, are provided in European Technical Assessment (ETA) certificates (e.g. ETA-09/0338 (2013)) which are issued by any recognised Technical Assessment Body (TAB).

In general, qualifications require audits of the management organisation and production control as well as material tests and systems tests. The latter is required to determine product specific strengths and factors which cannot be inferred from formulas. The regular test program consists of about 15 tests series (EAD 330008-02-0601 (2016), AC232 (2016)). Qualification relies on experimental tests while numerical simulations using advanced finite element analysis software are frequently used in the research, e.g. to improve the qualification guidelines (Figure 5).

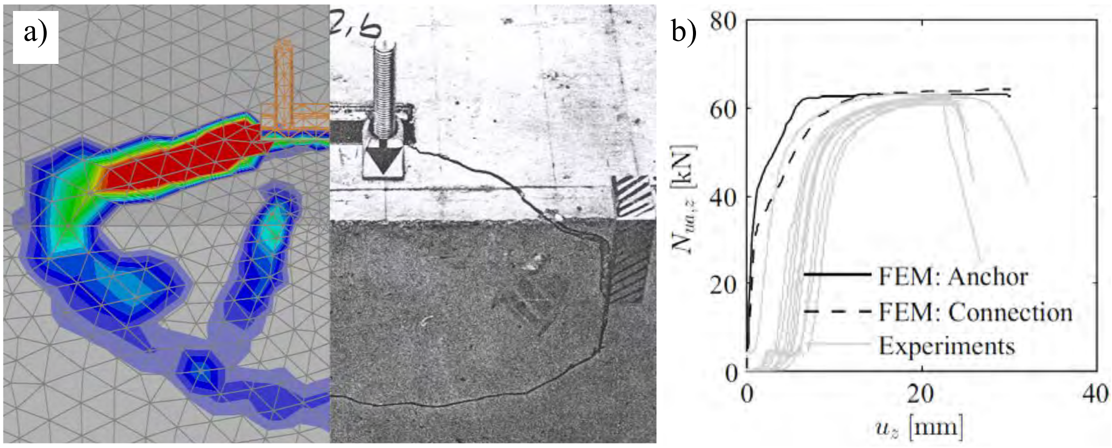

Figure 5. a) Example numerical simulation of experimental test (Potthof (2008)); b) Example load-displacement curves of simulations and tests (Kocur et al. (2016)).

3.2 Design of anchor channels with channel bolts

The latest revision of the design code for concrete structures in the *USA*, ACI 318 (ACI 318 (2014)), provides design rules for post-installed and cast-in anchors in Section 17 which were dealt with in Appendix D of previous editions. The design rules for anchor channel-channel bolt systems are not yet included. For this reason, AC232 provides amendments to the relevant clauses of ACI 318 to allow the *non-seismic* and *seismic* design of anchor channels and channel bolts.

In *Europe*, the design provisions for concrete anchors including anchor channels and channel bolts are provided in a prenorm (CEN/TS 1992-4 (2009)) which revision (FprEN 1992-4 (2016)) is currently in the formal vote process to become Part 4 of the Eurocode 2 (EN 1992-4 (2010)), the design code for concrete structures. An amendment (CEN/TR X (2013)) was drafted to allow the *non-seismic* design of anchor channels which channel bolts are loaded in the longitudinal direction. However, the *seismic* design of anchor channels and channel bolts is not yet codified but is expected to follow soon.

Whatever standard is applied, design of anchor channels and channel bolts is truly a challenging task which almost cannot be tackled without design software. Professional software solutions can be intuitively handled without lengthy training, take also attached fixtures (brackets, plates) into account, and provide the prints of the comprehensive structural analysis, bill of quantity, BIM objects etc. (Figure 6).

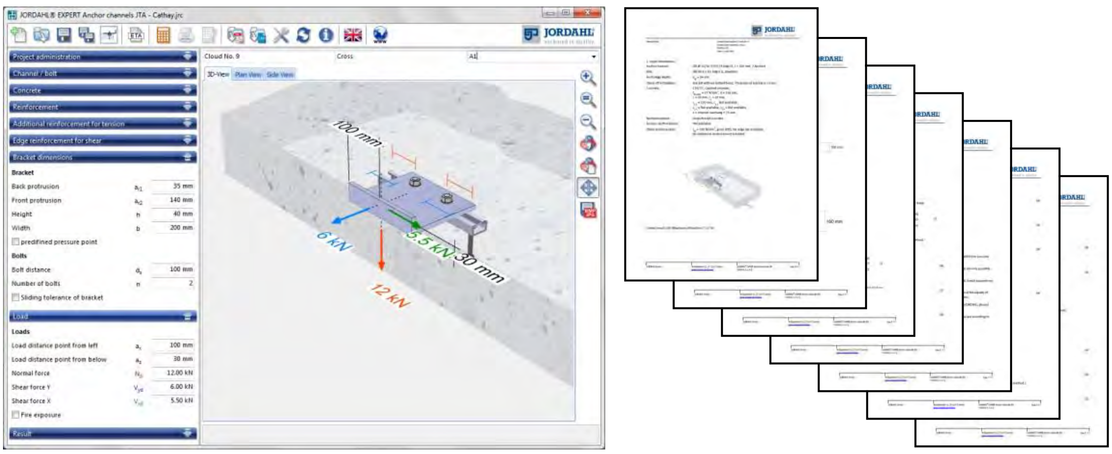

Figure 6. Screenshot of the graphical user interface of a professional anchor channel-channel bolt design software and the print of analysis ready for the checking engineer.

Summary

This paper gives the basic technical and regulative background of anchor channels and channel bolts used to connect components to reinforced concrete structures. The complex load bearing behaviour characterised by many different failure modes is briefly introduced. An overview of the relevant standards for qualification and design of anchor channel-channel bolt systems is provided to assist the specifier to select a suitable product and the designer to carry out a professional analysis for a safe and durable connection.

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