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SEISMIC SUITABILITY OF ANCHOR CHANNELS WITH CHANNEL BOLTS TO FASTEN E.G. CABLE MANAGEMENT SYSTEMS IN IMPORTANT INFRASTRUCTURE

Christoph Mahrenholtz[1], Pao-Chun Lin[2], Iain Baron[3], Sven Giesenbauer[4], Mary Liu[5]

[1] Head of Engineering, PohlCon, Germany (christoph.mahrenholtz@pohlcon.com)
[2] Assistant Professor, Department of Civil Engineering, National Cheng Kung University, Taiwan
[3] The Post-Tensioning Institute of Australasia, Australia
[4] Head of International Sales, PohlCon, Germany
[5] General Manager, Mormont Building Technology, China

ABSTRACT

The design of safety-relevant structural elements in important infrastructure has to take into account particularly high loads for example due to the impact of earthquakes. These loads may cause also extreme crack widths in reinforced concrete structures. It is crucial that also safety-relevant components anchored in reinforced concrete members do not fail, e.g. mechanical, electrical, and plumbing (MEP) works connected to walls and slabs.

Cast-in anchor channels with inserted channel bolts are a robust and reliable system for anchoring in reinforced concrete members, allowing the fail-safe connection for any component such as suspending brackets with cable trays. Advanced anchor channels with matching channel bolts were developed to cope with the extreme loading conditions to be taken into account for nuclear facilities.

To show their seismic suitability to anchor any component in reinforced concrete of critical infrastructure, advanced anchor channels were tested according to two seismic categories currently stipulated in qualification guidelines. Moreover, an innovative device to fill the gap between channel bolts and the holes in the baseplate of anchored components was developed to allow a more economical design.

INTRODUCTION

Anchor channels with channel bolts provide sound connections for any component, e.g. MEP works, attached to reinforced concrete structures, sustaining even if subjected to extreme loads. For the anchoring of safety-relevant components in important infrastructure, for example at the International Thermonuclear Experimental Reactor (ITER) project (Figure 1a), concrete fasteners suitable for seismic applications are imperative. Advanced serrated anchor channels with serrated channel bolts (Figure 1b) are particularly suitable as these transfer the loads in all directions by mechanical interlock.

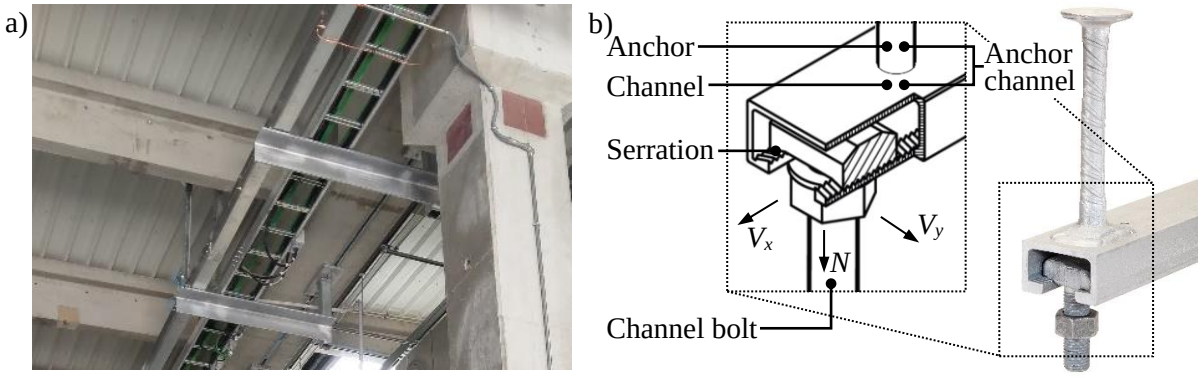

Figure 1. ITER project: a) Suspending brackets with cable tray and cable ladder anchored in reinforced concrete with b) advanced serrated anchor channels and matching serrated channel bolts.

BACKGROUND OF ANCHOR CHANNELS WITH CHANNEL BOLTS

The system of cast-in anchor channels with channel bolts, also simply known as anchor channels, was first invented in 1913 (Figure 2a), yet is nowadays more popular than ever. Today, anchor channels are made of headed anchors connected to C-shaped channels to accommodate T-shaped channel bolts. Conventional anchor channels with smooth channel bolts allow the transfer of tension loads N and shear loads V_y perpendicular to the channel. To enable the transfer of shear loads V_x also in the direction of the channel, anchor channels with serrated channel bolts were developed. These anchor channel-channel bolt systems are very useful, e.g. when installed vertically in walls to carry the load of components that require a precise tolerance compensation such as pipelines. Since the direction of seismic loads is unpredictable, serrated systems are especially suitable for seismic applications as these systems cope with loading in any direction. Advanced anchor channels have extra-large heads (Figure 2b), making the displacement during loading negligible which greatly simplifies particularly designs involving MEP works, often installed as statically indeterminate systems where differential settlement matters.

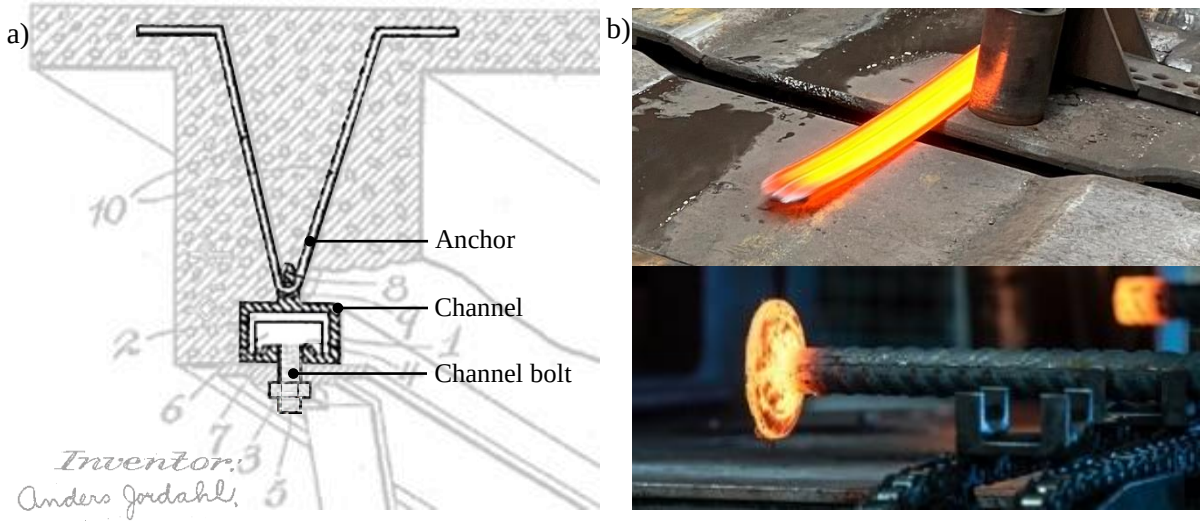

Figure 2. a) Anchor channels with channel bolts as invented 110 years ago (US Patent 1,155,243 1914), b) hot-forming of channels and anchors for contemporary advanced JORDAHL® anchor channels JXA-PC.

The installation sequence of anchor channels and channel bolts, aka T-bolts, is typically straightforward and simple for site installers to understand as shown below (Figure 3): The anchor channel is nailed to the formwork in accordance with the designer's positioning shown on the construction drawings and the concrete is then placed as normal. The formwork is stripped after the concrete has cured. Next, the filler material is removed from the T-bolt recess, after which the T-bolt can be inserted and rotated 90 degrees to engage with the channel lips. Finally, the baseplate to connect any component can be attached to the T-bolt.

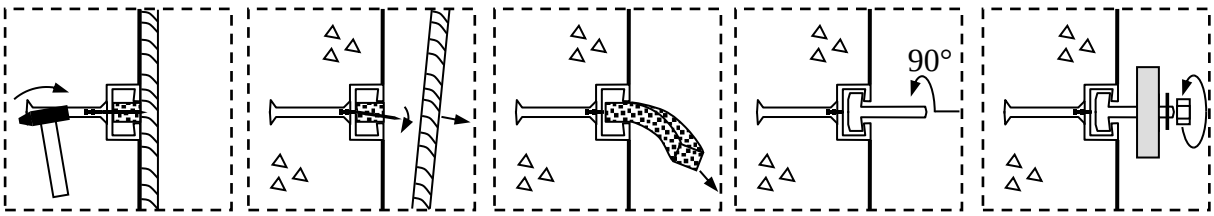

Figure 3. Anchor channel and channel bolt installation sequence.

Anchor channels with channel bolts became very popular for the connection of components with steel baseplates to the reinforced concrete structure mainly because of the following benefits (Mahrenholtz et al. 2022):

- Compensation of building tolerances by adjustable fit during installation of component baseplate
- No on-site welding required as for anchor plates, thus no fire risk and no quality issues
- No on-site drilling required as for post-installed anchors, thus no risk of cut reinforcement and no health issues (inhalation of silica dust, manifestation of white knuckle disease)
- Quick, easy, and fool-proof installation of anchor channels during construction
- Connecting, sliding, disconnecting of components using channel bolts during the complete life cycle

Design and Qualification

In Europe, the design provisions for concrete fasteners including anchor channels with channel bolts are provided in EN 1992-4 (2018). The design code for concrete structures in the USA, ACI 318 (2019), stipulates design rules for post-installed and cast-in anchors in Section 17. The design rules for anchor channels are not yet included. For this reason, amendments are provided in AC232 (2021). These Acceptance Criteria (AC) for anchor channels in the USA define required qualification tests to attain Evaluation Service Reports (ESR), e.g. ESR-2854 (2024). In Europe, qualified anchor channels receive European Technical Assessments (ETA) certificates, e.g. ETA-09/0338 (2024), if qualification tests have been successfully carried out according to the relevant European Assessment Document (EAD) which was recently updated as EAD 330008-04-0601 (2023). The authors are not aware of any specific design rules and qualification guidelines for anchor channels in Japan.

The design rules for concrete fasteners are very similar in Europe and the USA and have in common that the design takes into account about 20 possible failure modes of the anchor channel and channel bolt. A comparison of the situation in Europe and the USA may be found in Mahrenholtz and Sharma (2019). ESR and ETA not only certify qualification but also provide product-specific parameters required for the design. Due to the complexity of the design rules for anchor channels and channel bolts, structural engineers typically use software to design the fastenings, e.g. to anchor suspending brackets with cable trays (Figure 4).

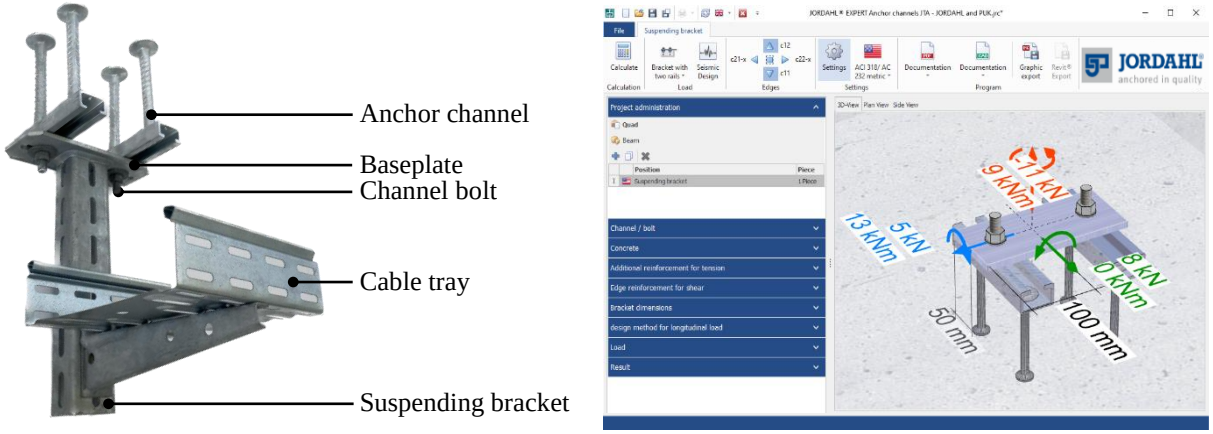

Figure 4. Anchor channel pair, a typical application in nuclear facilities to fasten e.g. suspending brackets with cable trays, and its representation in the design software (JORDAHL® EXPERT).

Single-point concrete fasteners for the connection of components to reinforced concrete structures (cast-in headed bolts as well as post-installed adhesive, wedge, undercut, and screw anchors) can be qualified for seismic applications according to two categories. The Seismic Category C1 which was originally developed in the USA in the 1990s. This qualification category was mirrored in Europe and amended by a more scientifically substantiated Seismic Category C2 in 2012. To date, only the C1 seismic qualification was stipulated for anchor channels in AC232 and EAD 330008-04-0601. It is arguable whether the introduction of the C2 seismic qualification for anchor channels would be meaningful (Mahrenholtz and Stollberg 2020), however, the Rules for Design and Construction in nuclear Civil Works (RCC-CW 2021) require C2. Comparative studies have shown that pursuing Seismic Category C2 is more demanding than C1 (Mahrenholtz and Wood 2020).

The purpose of two Seismic Categories C1 and C2 is now to allow the selection of a reasonable level of qualification to avoid over-engineered solutions and to foster economic approaches. To determine the suitable category in terms of performance requirements, the importance of the considered building and the seismicity of the site may be taken into account (Figure 5). Clearly, components for a building of low importance constructed in a region of low seismicity do not require any seismic qualification. On the contrary, the components for buildings of high importance should always have a high level of seismic qualification, no matter whether constructed in a region of low or high seismicity.

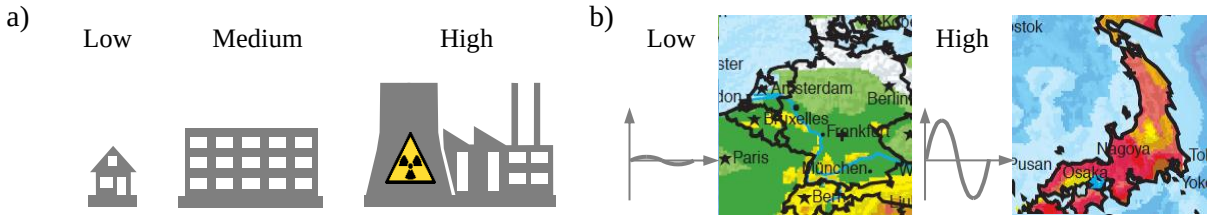

Figure 5. Seismic performance demand depends on a) the importance of the building and b) the seismicity of the site.

TESTS ACCORDING TO SEISMIC CATEGORY C1 AND C2

To compare the performance corresponding to the qualification according to the Seismic Categories C1 and C2, some tests are shown. The selected test series are part of a much larger test campaign carried out according to AC232 (2021) and EAD 330008 04-0601 (2023) discussed elsewhere (Mahrenholtz et al. 2023a). Since MEP works are typically suspended and because tension loading on concrete fasteners is generally more critical than shear loading, the cyclic tension test series are presented as an example.

Test Specimen and Test Setup

The tests were carried out on JORDAHL® anchor channels JXA-PC W53/34 with matching channel bolts JXB (Figure 6a). The diameter of the bolt was M16 and M20 and the strength grade was 8.8 (yield strength f_y = 640 MPa). The channel was $s + 2x$ = 320 mm long and furnished with two anchors. The shaft diameter d and head diameter d_h of the anchors were 14 mm and 43 mm, respectively, and the embedment depth h_{ef} was 179 mm. The width and height of the channel were b_{ch} = 53 mm and h_{ch} = 34 mm. The anchor channels were cast in concrete members with a tested compressive strength of $20 \text{ MPa} \leq f_{c,test} \leq 28 \text{ MPa}$.

For evaluation, the compressive strength would have to be taken into account by normalization (multiplication of tested ultimate load capacity F_u by the square rooted ratio of reference concrete compressive strength f_c = 25 MPa and tested compressive strength $f_{c,test}$) if the failure occurred in concrete. As will be discussed below, however, all tests failed in steel, and normalization was therefore not required. Moreover, the shaft diameter of the bolt is irrelevant as its capacity is not governing in this test series.

If compared with the test setup for monotonic tests used for the static (non-seismic) qualification, the test setup employed for cyclic tests requires in addition tie-down devices for the seismic qualification C1 and C2 test regimes to avoid uplifting of support and concrete member (Figure 6b).

Test Program and Test Results

Simulated seismic tension tests for C1 and C2 qualification are carried out with different cyclic load protocols (Figure 7), however, the procedure is in principle the same: In Phase 1 of the cyclic load tests, a pulsating tension load N is applied. Phase 2 is identical to the monotonic tests in tension, where the anchorage is loaded to failure to determine the residual ultimate load capacity $N_{u,res}$.

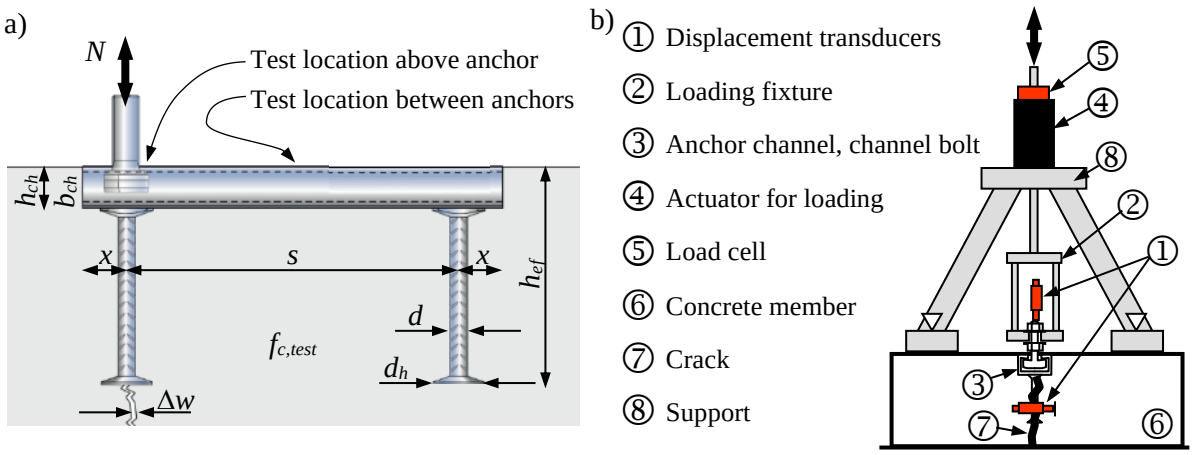

Figure 6. Tests on advanced JORDAHL® anchor channel JXA-PC with loaded channel bolt JXB: a) test specimen and b) test setup.

During testing, the displacements δ are recorded to plot load-displacement curves. Under the C1 test regime, the channel bolts are installed above one anchor of the channel. The C2 test regime also requires test series where the channel bolt is installed between the anchors of the channel if tested in tension. The result corresponding to the channel bolt position with the poorer performance is decisive.

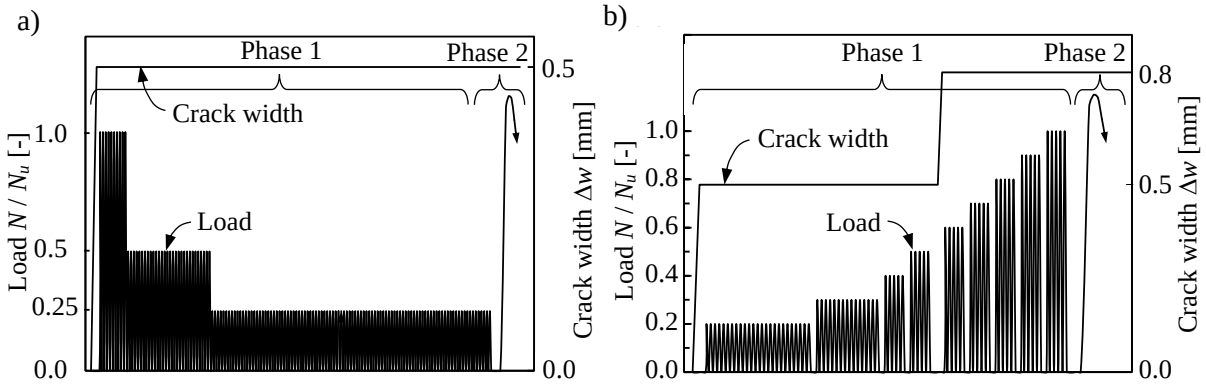

Figure 7. Protocol of cyclic tension according to a) C1 and b) C2 test regime.

The tests were carried out at accredited test labs. Each test series comprised 5 repeats (Table 1). The process of testing and evaluating simulated seismic tests is utmost complex and therefore, cannot be covered in detail here. In essence, the load level during Phase 1 is based on the mean ultimate capacity $N_{u,ref,m}$ determined in monotonic reference tests. If its ratio with the mean residual ultimate capacity $N_{u,res,m}$ tested in Phase 2, $N_{u,res,m}/N_{u,ref,m}$, is larger than the ratio limit criterion specified in AC232 (2021) for the C1 test regime and in EAD 330008 04-0601 (2023) for the C1 as well as C2 test regime, the capacity for seismic applications is identical to the capacity determined for static (non-seismic) applications. Otherwise, the capacity has to be reduced. For further details, we refer to Mahrenholtz and Wood (2020).

All test specimens completed the cyclic tension Phase 1 without failure and were thereafter loaded to failure to determine the residual capacity in Phase 2. The system always failed in steel due to deformation of the channel lips. Since tension load is deemed as the most critical loading direction, the tests demonstrate the outstanding performance of anchor channels with channel bolts due to the mechanical interlock between concrete and anchor as well as between channel and bolt. Since the failure mode of all test series was steel, the scatter of the ultimate load was overall low (larger for the C2 test regime than for the C1 test regime); the highest coefficient of variation was 6.3%.

Table 1: Test program and test results.

Test series (each monotonic and cyclic)		Repeats (each) [-]	Crack width Δw [mm]	Failure mode[1)]	Reference $N_{u,ref,m}$[2)] [kN]	Residual $N_{u,res,m}$[2)] [kN]	Ratio $N_{u,res,m}/N_{u,ref,m}$ [-]	Ratio limit criterion [-]	Criterion check
C1	above anchor	5	0.5	S	105.9	97.8	1.08	0.8	passed
C2	above anchor	5	0.8	S	103.4	107.5	0.96[3)]	0.9	passed
	between anchor	5	0.8	S	92.8	92.2 1	1.01		

Note: [1)] S: Steel failure (lip); [2)] m: mean value of test series; [3)] decisive

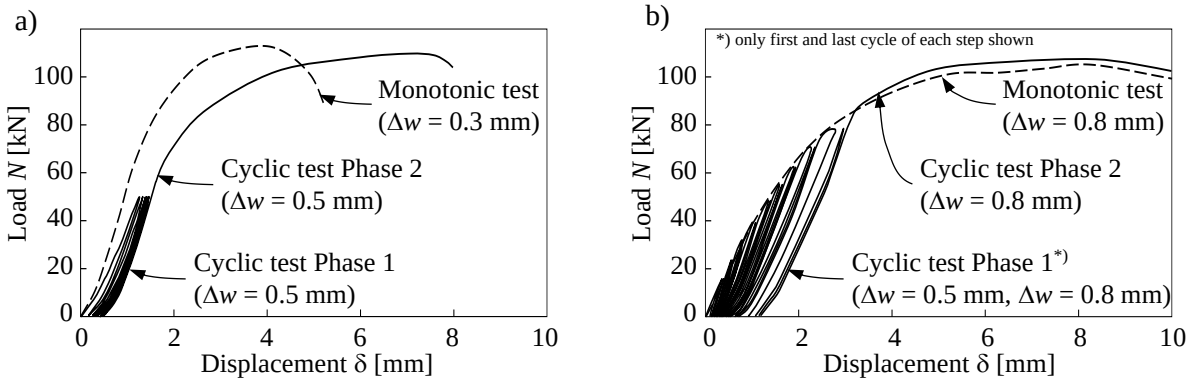

Figure 8. Example load-displacement curves for tension tests according to a) C1 and b) C2 test regime.

The other test results of the large test campaign were equally successful (Mahrenholtz et al. 2023a). In summary, the tested advanced anchor channels coped well with both seismic test regimes C1 and C2, fulfilling the ratio limit criteria stipulated for all cyclic tension, cyclic shear, and crack cycling tests. In other words, the tested advanced anchor channel carries under seismic loading in any direction as much as under static (non-seismic) loading conditions. This is not unusual even for conventional channels where anchors have standard heads, however, the advanced channel where anchors have extra-large heads develops about 8 times smaller displacements during crack cycling (Mahrenholtz et al. 2017). The displacement is then below 3 mm and can be neglected according to many regulations, e.g. RCC-CW (2021) and EN 1992-4 (2018), simplifying greatly the design particularly of statically undetermined MEP works such as pipelines. Note that ACI 318 (2019) is mute in this regard.

HAMMER EFFECT AND GAP FILLER

Generally, concrete fasteners are pre-stressed at a low level only. Therefore, the annular gap, also known as hole play, between the fasteners and the baseplate of the connected component may allow displacements when the baseplate is loaded to ultimo shear. Thus, transient seismic excitations cause cyclic displacements of the baseplate which then generate cyclic impulses acting on the fasteners when the displacement is larger than the gap width. This phenomenon, known as the hammer effect, amplifies the loads. To account for this adverse effect, the resistances (capacities) of all concrete fasteners (cast-in headed bolts as well as post-installed adhesive, wedge, undercut, screw anchors, and anchor channels) determined under quasi-static loads have to be reduced by 50% according to RCC-CW (2021) and EN 1992-4 (2018). For further background about the hammer effect, refer to Mahrenholtz et al. (2023b).

Also seismically loaded anchor channels experience the hammer effect when the baseplate pounds against the channel bolt after consumption of the hole play. Filling the gap between the baseplate and channel bolt as well as between the shaft of the bolt and the lip of the channel annihilates any

adverse hammer effect. To this end, gap filler sets are available, comprising a special nut and an insert (Figure 8). This design ensures that the shaft of the bolt never blocks the access hole provided for the injection nozzle of the adhesive cartridge applicator gun.

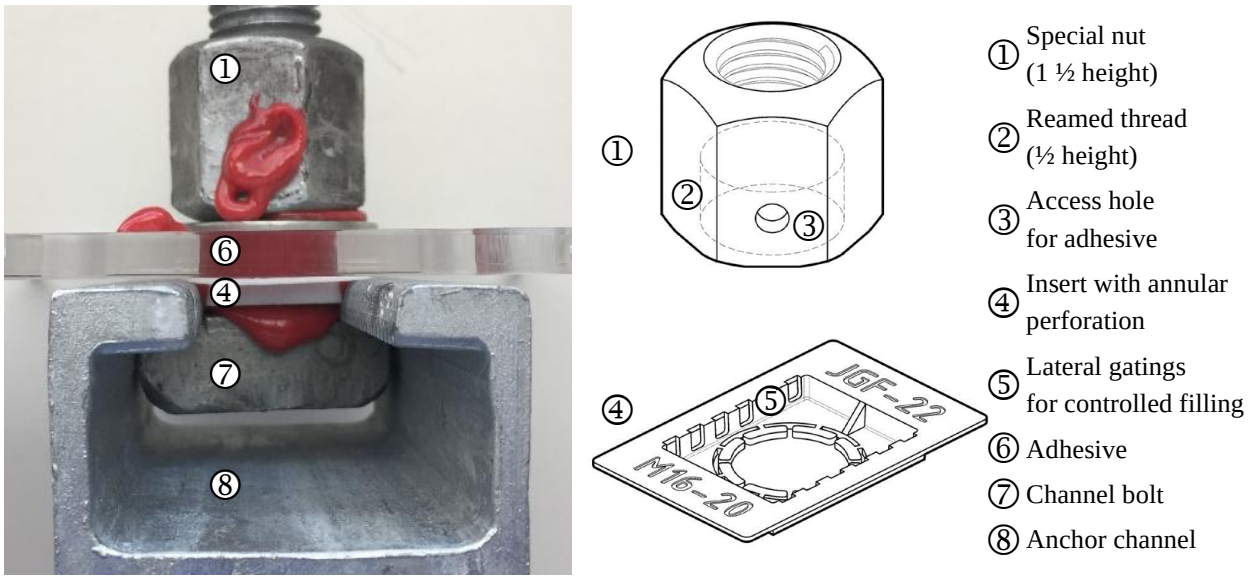

Figure 8. Elimination of the hammer effect requires the filling of the gap between the baseplate (acrylic glass for demonstration), channel bolt, and anchor channel using JORDAHL® gap filler JGF sets

The installation sequence of the special nut and insert is straightforward (Figure 9): Sliding the insert on the channel bolt to rest on the anchor channel, installing the baseplate, washer, and special nut, inserting the nozzle of the adhesive cartridge applicator gun into access hole after completion of all installation works, and injecting adhesive to fill the relevant gaps between the anchor channel and channel bolt as well as between channel bolt and baseplate.

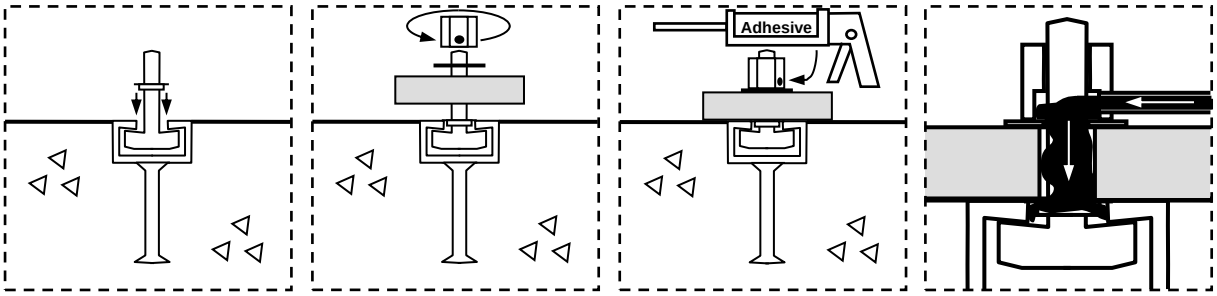

Figure 9. Gap filler installation sequence.

Tests have shown that gap filling significantly improves the load-displacement behavior with regard to the ultimate load and the corresponding displacement (Mahrenholtz et al. 2023b). Thus, gap filling efficiently prevents the hammer effect from happening during earthquakes. Note that the gap filler set requires no additional qualification. Gap filling is optional but if carried out, the 50% reduction is avoided, essentially doubling the design capacity and reducing the number of required connection points as well as the size of baseplates.

SUMMARY AND CONCLUSIONS

The anchor channel-channel bolt-system is introduced. The design codes and qualifications guidelines for concrete fasteners such as anchor channels with channel bolts are explained. It is pointed out that the design of concrete fasteners requires data from their qualification which must suit their intended use. The seismic suitability is shown by qualification tests according to the Seismic Category C1 or C2.

As part of a much larger campaign to certify advanced serrated anchor channels with matching serrated channel bolts for seismic applications, simulated seismic C1 and C2 tests in tension are presented as an excerpt of the total test program comprising also simulated seismic C1 and C2 tests in shear as well as crack cycling tests. The test results verify that the criteria stipulated in the qualification guidelines are met in both test regimes C1 and C2. Thus, the seismic design capacity is equivalent to the static (non-seismic) design capacity. The outstanding performance makes anchor channels with channel bolts a perfect choice for seismic applications. This holds particularly for advanced channels whose anchors have extra-large heads, ensuring negligible displacements even under severe seismic loading. The use of these advanced anchor channels thus greatly simplifies the design of connections for any component in critical infrastructure. Moreover, gap filler sets allow the filling of the gap between the channel, bolt, and baseplate of the connected component and thus double the seismic design capacity.

The views expressed in this paper are the views of the authors only and do not necessarily reflect the views of PohlCon, the National Cheng Kung University, The Post-Tensioning Institute of Australasia, and Mormont Building Technology.

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