Shear tests on demountable precast column connections

Jaakko Yrjölä | Jan Bujnak

Peikko Group, Department of R&D Connections, Lahti, Finland

Correspondence
Jaakko Yrjölä, Peikko Group, Department of R&D Connections, Voimakatu 3, 15170 Lahti, Finland.
Email: jaakko.yrjola@peikko.com

Abstract
Lately, there has been increasing demand for structural solutions and building technologies with minimized CO₂ footprint. One way to approach the carbon neutrality is through reuse of structural components. In order to enable economic reuse of precast concrete elements, their connections must be designed to allow an effortless dismount. While dismount ability provides additional value to the structure, it cannot have a negative impact on other crucial properties of the connection. One of those properties is the load-transfer capacity. While the impact of improved demountability on the load-transfer of axial forces is negligible, the capacity of such joints to transfer shear forces can be questioned, as it is often assumed to rely on the friction generated along compressed section. This paper studies the effects of an improvement of demountability on the shear-transfer system in a bolted joint of precast concrete columns.

KEYWORDS
bolted connections, dismount ability, precast concrete element, reusability, shear-transfer

1 | INTRODUCTION

The technology of precast concrete offers numerous benefits to different stakeholders of the value chain in the construction industry. Precast elements are usually manufactured under controlled conditions in factories, thus allowing the production of elements of high quality and precision. Using precast structures also allows optimizing the efficiency of works on site, thus enabling a faster construction process.

Bolted connections (see Figure 1) are one of the most common ways to connect precast structures on site due to numerous practical benefits. For example, Brazilian Arenas for the World Cup 2014 were greatly constructed from prefabricated concrete structures, due to several crucial constraints, like tight schedule and strict cost control. Even 90% of the construction were prefabricated in some cases. As of today, it can be concluded that bolted connections further improve the competitiveness of precast structures by allowing time-saving installations without a high amount of manpower.

The concrete industry is one of the biggest consumers of raw materials, and over 10 billion tons of sand and natural rocks, as well as 1 billion tons of water are used annually for concrete production around the world. In addition to consumption of raw materials, the concrete industry has also a significant influence on CO₂ emissions and it consumes a great deal of energy every year. A production of one cubic meter of concrete accounts for...
approximately 0.2t of CO2 emissions.\(^4\) Portland cement, known as hydraulic binder in modern concrete, is a product also responsible for a large amount of CO2 emissions.\(^4\) The use of clinker as part of cement makes the embodied energy and CO2 emissions relatively high, while about one ton of CO2 is generated for each ton of clinker.\(^4\)

In addition to consumption of raw materials and energy, as well as high CO2 emissions, over 11 billion tons of waste is generated due to demolition and construction work.\(^3\) About 50% of this quantity is generated from concrete waste.\(^5\) It is a fact, that a considerable amount of concrete buildings and structures around the world end their service life and are demolished, while their elements still possess some residual value and could serve for longer time. The linear cycle model, also known as “cradle-to-grave,” stigmatizes buildings made from concrete structures. It prevents reusing and flexibility, and very little attempts have been made to reuse concrete structures of buildings ending their service life. However, studies have pointed out that significant environmental benefits could be achieved by reusing concrete structures, including energy savings.\(^4\)

One of the most significant reasons for the lack of reusability is the lack of adaptability of connections between structures. In order to improve the reusability of concrete structures in new buildings, connections should be developed to allow cost-efficient dismount without compromising with the other required properties.\(^6\) Based on that, the ecology of concrete structures could be significantly improved by considering the disassembly in the design of connections. The above-mentioned facts have been acknowledged by the European Commission as some of the cornerstones of the Circular Economy Action Plan\(^7\) that defines a roadmap for reaching the carbon neutrality of the construction industry in 2050. Among others, the Action Plan implies that new material recovery targets will be set in EU legislation for construction and demolition waste in foreseeable future.

Bolted connections have significant potential to be a key for reusability of concrete structures in the future.\(^8\) While such connections can be already considered as demountable to some degree, improvement of detail is required in order to allow even more economical and efficient way of dismount. Bolted connections typically consist of an anchor bolt or coupler embedded in one concrete element and a steel plate with oversized hole (a column or a wall shoe) anchored in the other element. The joint between precast concrete structures is usually formed by tightening the bolt to the end plate of the column or shoe. 

**FIGURE 1** Precast column connections with column shoe inserts\(^1\)

**FIGURE 2** Common connection between precast structures
insert and grouting the gap between connected structures with unshrinkable cement-based mortar (see Figure 2). A gap, on the contrary, is preferred to provide some installation tolerance on a construction site, thus an opportunity to level a structure, like a column, after the assembly. Grouting can be considered as the biggest constraint on the disassembly of the connection, since it binds structures with an adhesive bond. Based on that, the most promising way to improve dismount ability is to either get rid of the grout or to reduce its adhesive bond. From those two alternatives, only the latter has a practical premise, since removing the whole grout reduces too much flexibility on a construction site. Reducing the adhesive bond between the grout and the connected structures is expected to have an influence on frictional properties of the joint faces.

Precast column base connections must include at least the following properties in order to work as practical and economical solution; load transfer in normal use and in accidental situations, installation tolerances, resistance against environmental exposure, integrity and insulation. Introducing the demountability as a novel feature cannot disable the other properties of the connection. Transfer of the horizontal shear forces is the property most likely affected due to reduction of the friction properties.

Demountable connections for precast concrete structures are just in the beginning of their journey, thus very little research has been done for their performance in horizontal shear. Other researchers have also remarked that there is a lack of research in overall, even with regards to the shear performance of traditional bolted column connections. The performed study provides novel information about the topic not studied before and offers first insight to the functionality of the demountable connections.

2 | BOLTED PRECAST COLUMN CONNECTION

Typical bolted precast column connection is presented in Figure 3. A joint comprises from three main structural parts: (1) Column shoes as column inserts, (2) grouting and (3) Anchor bolts as base structure inserts.

Anchor bolts are typically B500B rebars with threads protruding from the base element, produced under industrial production control with performance validated by European Technical Assessments ETA 02/0006. Instead of using column shoe inserts, steel column is usually connected to anchor bolts from welded base plate. While base plates are provided with precise clearance holes, column shoes are manufactured with some installation tolerance. As a result, there may not be a direct contact between anchor bolts and column shoes at the unloaded state. Even though part of the grout may be poured between the anchor bolt and the column shoe during grouting, reliable direct contact can be provided only by welding or using filler material.

Both ends of the anchor bolts are properly fixed, and thus slip of the anchorage is eliminated. Joint faces of the traditional precast column base connections are not intentionally roughened by any means and may be classified as smooth according to EN 1992-1-1, 6.2.5, which is realized as a free surface left without further treatment after vibration.

In case there is no contact between a shaft of the anchor bolt and the column shoe, direct force-transfer cannot occur without a shear slip. However, a friction effect is generated from the tightening of the upper nuts of the anchor bolts against column shoes. Slip resistance, based on that effect, can be estimated according to EN 1993-1-8, 3.9.

3 | SPECIFICATION OF THE DEMOUNTABLE PRECAST COLUMN CONNECTION

As stated before, the most likely way of improving the demountability is to prevent or reduce adhesive bond by using a release agent. The functionality of the concept has been already proven by Fennis et al. Two different kind of release agent systems have been suggested by the authors: demoulding oil and thin steel plates. Principle of the modified connection detail is presented in Figure 4.
Two major changes should be provided: (1) avoid grouting of the recess boxes by replacing with heat resistant insulation material and (2) provide a release agent for either reducing or preventing the adhesive bond. In addition to the dismount of the precast column, there is also a possibility to reuse a foundation as well. In order to do it, common anchor bolts should be changed to anchoring couplers, which allow screwed connections with demountable threaded parts (see Figure 5).

Two different alternatives with different release agent systems are studied (see Figure 6). Separation between the grout and the structures is provided by demoulding oil (figure on the left) and by thin steel plates (figure on the right). In right-hand figure, there is a small unintentional gap between the lower thin plate and foundation, which should be filled with filler material, having at least the same strength than grout.

4 | TEST ARRANGEMENT

Shear tests with traditional and demountable connections of precast bolted connections took place in the beginning of January 2020. In test setups, four different connections were loaded by shear to failure. Details of the different setups are given in Table 1 and characterized in Figures 4 and 5. Only bolt types and release agent systems were altered between different variations.

Each test setup was arranged with the same size of precast columns \((350 \times 350 \times 1500 \text{ mm}^3)\) and foundation structures \((450 \times 700 \times 1400 \text{ mm}^3)\). Illustrations of both structures are presented in Figure 7. As stated earlier, clearance gaps of the column shoes are always slightly

![Figure 4](image-url)  
**Figure 4** Precast column base connection with improved demountability

![Figure 5](image-url)  
**Figure 5** Common anchor bolt (left) and anchoring coupler with threaded bar (right)

![Figure 6](image-url)  
**Figure 6** Studied alternatives for demountable precast column connections
bigger than diameter of the bolt thread. In those tests, M16 bolts were used, and associated column shoes (thickness 15 mm) had 25 mm clearance gaps. Location of the bolts inside clearance gaps were measured beforehand and those measures are explained in Figure 8 and Table 2. Bolts are also identified with numbers 1 to 4 in Figure 8.

In test setups, the foundation structure was supported on a strong floor and the other end of the column on a free end support. The foundation structure was held firmly against the floor with a hydraulic jack, while another jack was used for applying the load. The load was introduced to the end of the column element and transferred through a steel bar. The approximated lever arm to the foundation surface equalled the thickness of the grout, 50 mm, respectively. Photograph from test setup 03 is presented in Figure 9 and the presentation of the test arrangements is illustrated in Figure 10.

Compressive strength of the precast columns, base structures and grout were measured by breaking $150 \times 150 \times 150$ mm$^3$ cubes. Measured strengths are given in Table 3. Average strength of the grout was approximately 59 MPa.

![Figure 7](image1.png)  
**Figure 7** Schematic figures of tested precast structures

![Figure 8](image2.png)  
**Figure 8** Identification of bolts and measured clearances
Before loading the connection to failure, the applied load was increased twice to about 30 kN and unloaded back to zero. These load cycles caused a setting of the structure due to initial deformation. The setting was captured by measuring the irreversible part of the displacement as presented in Table 4 for all test setups.

Strain gauges were glued to every anchor bolt and placed on and under the threaded part, at the level of foundation surface (see Figure 11). In addition to strain measurements, also relationships between the applied force and the displacement were captured.

5 | TEST RESULTS

The load-displacement relationships during the whole test period for different test setups are graphed in Figure 12. Graphs start from the last loading cycle, where connections were loaded to failure. All connections shared a very similar behavior until a vertical load of approx. 40 kN (see Figure 13). After that, the stiffness against horizontal displacement started to vary between specimen, demountable connection with thin steel plates acting as the least stiff.

Strains were measured next to the threads during the whole test period. Measured strains with respect to displacement range 0–2 mm from test setup 01 are presented as an example in Figures 14-17. From recorded strains, it is possible to calculate the bending moment $M$ in the bolts. For that, we need the following balance equations.

\[
\varepsilon_c = \frac{F}{EA} - \frac{M}{EI} \frac{d_b}{2}
\]

(1)

\[
\varepsilon_t = \frac{F}{EA} + \frac{M}{EI} \frac{d_b}{2}
\]

(2)

In these equations:
**INTERPRETATION OF TEST RESULTS**

While bending moment values mostly grow with respect to a displacement range 0–2 mm in traditional connections 03 and 01, different patterns are observed in demountable connections. At first, bending moment values increase similarly as in traditional connections, but then reach some peak value and start to reduce. Eventually, even the direction of bending is changed in some bolts of the demountable connections. This indicates that there is a change in the load-transfer mechanism.

As described in chapter 4, the only differences between the traditional and the demountable connections were the treatment of joint faces and the character of the anchor bolt. Based on measured strains, the authors suggest the following model for initial load-transfer between the column end and the foundation (see Figure 22).
It is the view of the authors, that the two parameters governing the initial load-transfer mechanism are the bending stiffness of the bolt and the stiffness of the grout. Stiffening effect of the grout has been studied by Shaheen et al. Shear is transferred from column to bolts and without grout the whole shear would be transferred to the foundation as bending and shear of the bolts, while direction of bending was opposite than observed at the
beginning of the tests. However, the grout acts as lateral restraint for the bolt shafts and the amount and direction of bending in the bolts depends on the stiffness of the compressive strut formed in grout. Stiffness of the compressive strut, in turn, depends on the mechanical properties of the grout material, but also on the contact between the grout and foundation surface. Since there is no significant distinction in connections between the bolt and the column shoe with different connection types, it is highly likely that performance observed with demountable connections are mainly due to loss of grout stiffness, and yet slipping between the grout and the foundation.

Even though the lever arm of the applied force was minimized, it was not possible to fully eliminate it. Presence of bending moment may lead to two kind of contributions to the load-transfer system: tensile strain of Bolts 1 and 2 may influence the load-transfer between the bolts and the column shoes, and friction forces may appear in the compression side of the section to improve the stiffness against horizontal displacement. However, resulting axial forces $F$ from Equations (1) and (2) are not very significant in Bolts 1 and 2 along the displacement range 0–2 mm. This would indicate that unavoidable lever arm did not have a clear impact on the difference in observed performances between the traditional and the demountable connections.

### 7 ACCEPTABILITY OF THE PERFORMANCE

Even though all connections sustained an ultimate load about 300 kN and beyond, that was also associated to significant horizontal displacement of the column end. In practice, such displacements are not allowed to occur in service use, but only in accidental cases. For service use, the acceptability of the performance cannot be assessed such straightforwardly. One way to set the limit for performance in service use, is to allow only reversible deformations and thus elastic behavior of structural parts. Here it may be studied from the linear and nonlinear parts of bending moment diagrams of the bolts (see Figures 18–21). When the bending moment curve of the bolt reaches its initial peak value, thus linearity ends, the load-transfer mechanism is supposed to change due to irreversible deformation in restraining the strut by the grout. That is considered as a limit for assessing the acceptability of the performance of demountable connections.

According to the results, the load-transfer mechanism is influenced by demountability, and the stiffness against horizontal displacement is reduced already with small displacements. However, current design method may still possess enough conservativity to provide a safe design also for demountable connections.

Currently, there is no unified design method for shear resistance of the column shoe connections, but the design method described in Technical Report 068 of European Organization for Technical Assessment\(^\text{15}\) is based on the design principles of EN 1993-1-8.\(^\text{13}\) There, the shear resistance of the column shoe connection is defined as the resistance of the shoe itself or the anchor bolt, whichever is smaller. In practice, the shear resistance of the bolted precast column connection is pretty much always limited by the resistance of the anchor bolt. Only bolts in the compression side of the section are consider transferring the horizontal shear. Design equations for the resistance of the single shoe - bolt pair are formed as follows:

\[
V_{Rd} = k_s V_t = k_s \min (F_{1,vb,Rd}, F_{2,vb,Rd})
\]

where $F_{2,vb,Rd}$ is the shear resistance of the anchor bolt, obtained from
In these equations:

\[ F_{2,\text{vb},Rd} = \frac{a_b \cdot f_{\text{bolt,u}} \cdot A_{\text{bolt}}}{\gamma_{M2}} \]  

\[ a_b = 0.44 - (0.0003 \text{ MPa}^{-1}) \cdot f_{\text{bolt,y}} \]  

Equations (3)-(5) are used for calculating the characteristic resistance of both tested connections without release agent; the column shoe connection equipped with anchoring couplers and threaded bars and the traditional column shoe connection equipped with anchor bolts. The maximum service loads are then defined by dividing the characteristic resistances by the partial load factor, approx. equal to 1.4 as average of ultimate limit state load factors for permanent (1.35) and variable (1.5) loads according to EN 1990. Initial information for the calculations is given in Table 5 and is taken from the technical approvals of the products; ETA-02/0006 for anchor bolts and general product approval Z-30.6-72 for anchoring couplers. The material safety factor \( \gamma_{M2} \) is 1.0 to determine the maximum service load. The maximum service loads are added to the diagram in Figure 13 but showing only the connections with release agent and the updated diagram is represented in Figure 23.

8 | CONCLUSIONS

According to results, the stiffness against horizontal displacement reduces with smaller displacements in the demountable connections than in the connections without release agent. The load-transfer mechanism of the demountable connection with thin steel plates remains fairly linear up to a slip about 0.5 mm and about 1 mm for the case of the connection with oiled joint faces. Applied loads associated to those slips were about 45 and 80 kN, respectively.

Based on EN 1993-1-8, the maximum service load for connections equipped with anchoring couplers is about 44.2 kN and the maximum service load for traditional connection is about 35.5 kN. This implies that a design based on EN 1993-1-8 would be conservative for both traditional and demountable connections of precast columns. However, further experimental research is needed to confirm this assumption against possible variations due to parameters such as concrete strength and size effect.

In practice, column connections are usually loaded also by axial forces due to eccentricity of the acting horizontal load and/or compressive vertical load. Those forces generate friction forces, which can take part or all of the horizontal shear. In this paper we have shown that load-transfer mechanism provided by other mechanisms, when friction forces does not exist, is indeed influenced by demountability. Next step of the research is to clarify, how the use of those release agents influences the frictional properties between the joint faces and yet, the overall load-transfer mechanisms under various loading.

DATA AVAILABILITY STATEMENT

Data available on request due to privacy/ethical restrictions.

ORCID

Jaakko Yrjölä https://orcid.org/0000-0002-9992-1795
Jan Bujnak https://orcid.org/0000-0002-8230-3114

REFERENCES

1. HPKM ETA Technical Manual Peikko Group 002. 2014. www.peikko.com/products/product/hpkm-column-shoe/
2. Stucchi F, Coelho UM, Fujii G, Corres Peiretti H, Soriano Martin J, Doniak S. Corinthians arena – 2014 world cup, design and construction. Struct Concr. 2016;17(5):698–709. https://doi.org/10.1002/suco.201600086.

3. Mehta KP. Greening of the concrete industry for sustainable development. Concr Int. 2002;24(7):23–8.

4. Salama W. Design of concrete buildings for disassembly: an explorative view. Int J Sustainable Built Environ. 2017;6:617–35. Accepted March 31, 2017.

5. Tam VWY. Economic comparison of concrete recycling: a case study approach. Resour Conserv Recycling. 2008;52(5):821–8. https://doi.org/10.1016/j.resconrec.2007.12.001.

6. Lahdensivu, Jukka. Huuhka, Satu. Annila, Petri. Pikkuvirta, Jussa. Kölö, Arto. Pakkala, Toni. 2015. “Betoni-elementtien uudelleenkäyttömahdollisuudet. Tampere University of Technology. Department of Civil Engineering. Structural Engineering. Research report 162

7. Circular Economy Action Plan. For a cleaner and more competitive Europe. 2020. European Commission

8. International Standard ISO 20887: Sustainability in buildings and civil engineering works – Design for disassembly and adaptability – Principles, requirements and guidance. 2020. ISO 20887:2020(E)

9. Shaheen MA, Tsavdaridis KD, Salem E. Effect of grout properties on shear strength of column base connections: FEA and analytical approach. Eng Struct. 2017;5:2–21. https://doi.org/10.1016/j.engstruct.2017.08.065.

10. Bahleda F, Bujňaková P, Koteš L, Hasajová L, Nový F. Mechanical properties of cast-in anchor bolts manufactured of reinforcing tempcore steel. Materials. 2019;3:1–13. https://doi.org/10.3390/ma12132075.

11. European Technical Assessment ETA-02/0006. Issued on 13th of November, 2017.

12. Eurocode 2: Design of concrete structures. Part 1–1: General rules and rules for buildings. 2004.

13. Eurocode 3: Design of steel structures. Part 1–8: Design of joint. 2005.

14. Fennis, S., Visser, G., van Vliet, E. 2019. Circular Bridge at Reevesluis Kampen, the Netherlands. fib Symposium 2019, Concrete – Innovations in Materials, Design and Structures. 27–29 May, Krakow, Poland. p. 661–662

15. EOTA TR 068. 2019. “Design of structural connections with column shoes”.

16. European Technical Assessment ETA-18/0037. Issued on 15th of November, 2018.

17. European standard EN ISO 898-1: Mechanical properties of fasteners made of carbon steel and alloy steel – Part 1: Bolts, screws and studs with specified property classes – Coarse thread and fine pitch thread. ISO 898-1:2013. 2013.

18. Eurocode – Basis of structural design. 2002.

19. Allgemeine bauaufsichtliche Zulassung Z-30.6-72. Issued on 7th of April 2017; 2017.

**AUTHOR BIOGRAPHIES**

Jaakko Yrjölä
Senior Structural Engineer
Peikko Group, Department of R&D Connections
15170 Lahti, Finland
jaakko.yrjola@peikko.com

Jan Bujnak
Vice President, Product Development, Connections
Peikko Group, Department of R&D Connections
15170 Lahti, Finland
jan.bujnak@peikko.com

**How to cite this article:** Yrjölä J, Bujnak J. Shear tests on demountable precast column connections. *Structural Concrete*. 2021;1–11. [https://doi.org/10.1002/suco.202000635](https://doi.org/10.1002/suco.202000635)