# CONNECTIONS

Peikko guides you towards a faster, safer, and more efficient way to design and build.

1*2021

30 years of defining the game

## The journey of a lifetime

### The respected gravity foundation

Reaches 7th generation

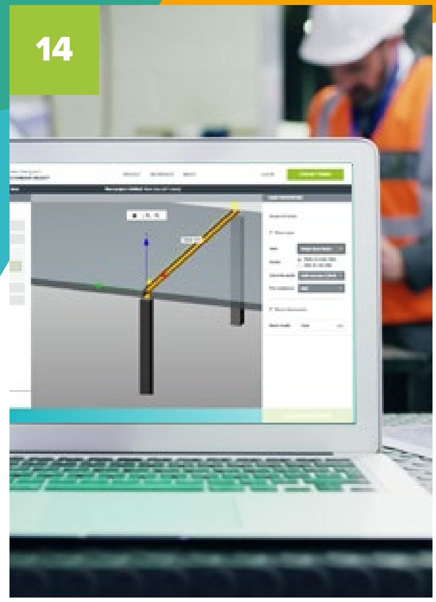
PEIKKO WHITE PAPER

- Bolted connections for precast structures – enabling circularity without compromising performance
- Composite Columns: Corbel design development
- New generation of column shoe connections

peikko®

ISSUE 1 | 2021

# Content



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## CONNECTIONS


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**ON THE COVER:**

With a track record of more than 30 years, Peikko is a pioneer in bolted column connections. We are always working on bringing the best solution for our customers with further development and optimization.

# Lowering $CO_2$ emissions is in everyone's interest

COVID-19 has dominated the air space during the last year, without a doubt. The crisis has had a great impact on the world and the way we do business. It's been encouraging to see the fighting spirit and resilience of people and businesses during these uneasy times.

However, we had challenges to face even before the Coronavirus. Climate change is one of them – and it won't go away unless we do something about it.

Almost all human activities end up producing $CO_2$ emissions, with the building industry being – sadly – among the largest culprits. That's why we at Peikko are constantly working towards as low carbon footprint as possible.

We must always ask ourselves: Is there a way to avoid emissions altogether? And if the emissions are inevitable: Is there a way to minimize them?

In the minimizing game, we have already had some great successes.

For example, the recently launched DELTABEAM® Green utilizes recycled materials and optimized logistics for 50% lower $CO_2$ emissions when compared to beams manufactured using virgin steel.

Our wind turbine foundations have been constantly developed to use less materials for ease and efficiency in construction, as well as lower prices and reduced emissions. The new Gravity7 foundation is a prime example of that.

And lastly, exciting horizons can be seen in circular construction, which Peikko has already pioneered. You are welcome to take part in the Construction Goes Circular conference here in Finland on October 12 – for more information, go to **constructiongoescircular.com**


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30 years of defining the game

# The journey of a lifetime

What does it take to change a whole industry? Being a forerunner in a conservative industry requires more than just technical knowledge. One needs to have courage and persistence. The ability to dive headfirst into challenges and turn them into possibilities. The willingness to create your own roads to an undiscovered territory and learn things as you go.

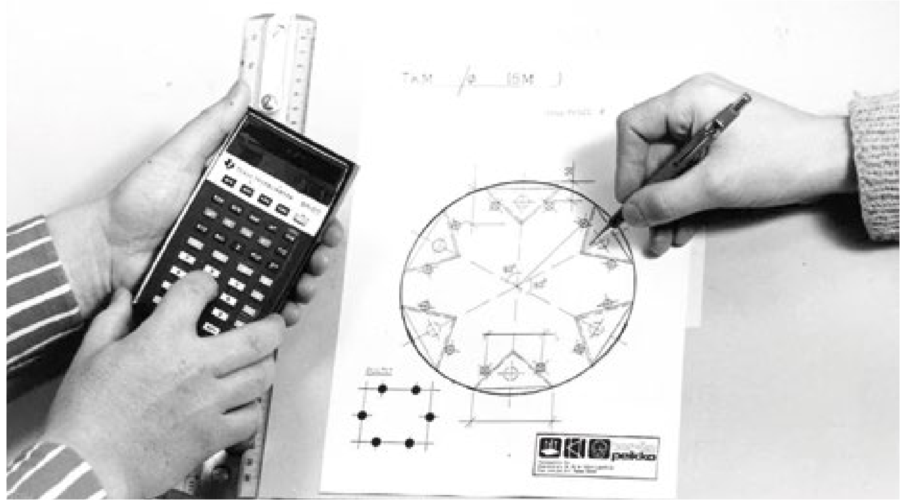
30 YEARS
DEFINING THE GAME
Bolted column connections

**What if we used bolts instead?** It was just a thought. There was no way on knowing what it would grow into. This is the story of bolts and of how bolted column connections became the industry standard.

### HPKM® – THE ICONIC PRODUCT THAT IGNITED THE FLAME

The idea of bolted column connections was first initiated in the mid 1980's. Because of the conservative nature of the construction business, many thought it was going to be difficult to get an entirely novel method accepted to the market. But little did anyone know – it was a success. By 1991, the idea was brought to life with a revolutionizing product line: HPKM® Column Shoes.

The design of HPKM® was game-changing. It offered a smaller, lighter solution that was strong and easy to use. Introducing column shoes dramatically changed the speed of construction process down to 10 minutes for each column. Plus, the need for continuous column support was eliminated.



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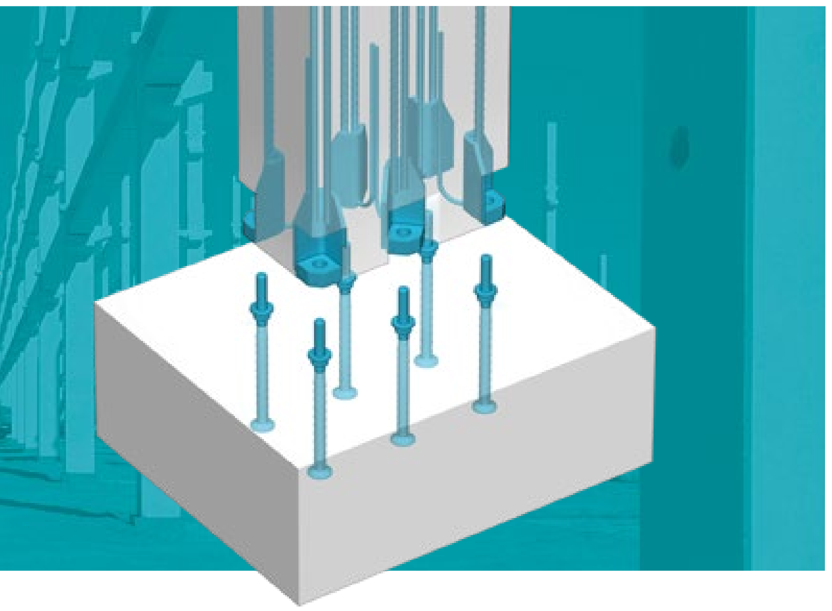


> **Column shoes dramatically changed the speed of construction process down to 10 minutes for each column.**

The innovation of HPKM® was only the beginning for Peikko. Four years after the initial launch, the larger PEC® Column Shoe was launched along with PPM® Anchor Bolts. This combination used even higher strength steel and enabled a higher load bearing.

### TO THE EUROPEAN MARKETS, AND BEYOND

After some success in the domestic market of Finland during the early 1990's, Peikko decided to take a step towards international markets. As in any industry, exporting and international operations in a new market is always a high-risk action that takes time to produce profit. However, Peikko had an excellent possibility of success at hand as the business competition was still non-existent.

In researching the markets, Peikko found out their brand and concepts were unknown in Central Europe. Peikko saw this as the perfect opportunity, and so in 1993, the bolted column connections were introduced to the German market. Soon after, Peikko's resellers launched the bolted column connection also in Sweden and Norway. A few years later in 2000, Peikko also entered the Spanish market, quickly gaining a credible market position. Peikko's internationalization was proving to be successful.

### RELENTLESS CREATION OF THE INDUSTRY STANDARD

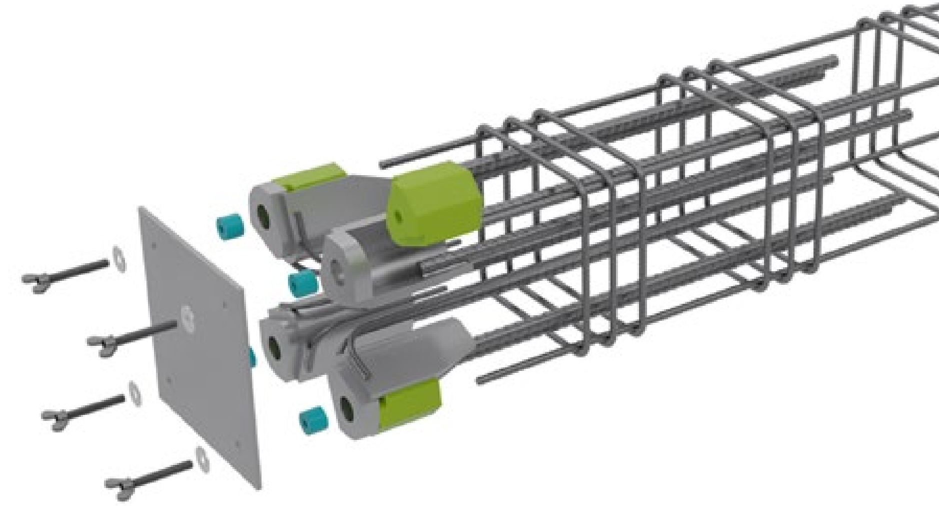
During internationalization, Peikko focused on learning from the new markets and developing their products. Special attention was given to obtaining ETA assessments and CE markings. The work around ETA began in 2003, when Peikko started to create standards for bolted column connections and develop standardized procedures to assess safe performance.

As new international market areas were landed, Peikko's position was further solidified. In 2005, Peikko column shoes entered the Russian markets and in 2009, Peikko worked on its first seismic projects with customers in Turkey. At this time, Peikko made its largest single R&D investment as Peikko Designer® software was launched. With this software, Peikko wanted to make designers' work as reliable and easy as possible and give them some room for creativity.

After years of hard work, Peikko completed the pioneering development of the ETA performance requirements and test procedures for bolted column connections in 2010. Concurrently, the market was growing as per usual, as Peikko entered the APAC and Chinese markets in 2011, and later on established an office in Singapore.

In 2013, Peikko reached a big goal: the ETA was granted to bolted column connections, which were soon followed by performance-based CE markings. Becoming the industry standard was officially reality, since no other company had been granted the ETA ever before. But still, Peikko was looking forward – there's always room to improve.

> **The most recent huge innovation for Peikko was launched this year, when BOLDA® was introduced.**



### FROM CHANGING TODAY TO CHANGING THE FUTURE

Over the last 30 years, Peikko has improved a lot about the design of their column shoes. A huge amount of product testing, with everything from concrete and fire testing to seismic testing, has been done in order to create the best possible products. In 2017, Peikko introduced the first energy-dissipating, seismic-proof precast bolted column connection.

Peikko has grown into a successful global company. Despite this success, the main goal of Peikko remains ever the same: to make its customers' building processes faster, safer, and easier. Peikko's R&D depends highly on the customer needs and the strong culture of listening and openness are always at the heart of Peikko's operations.

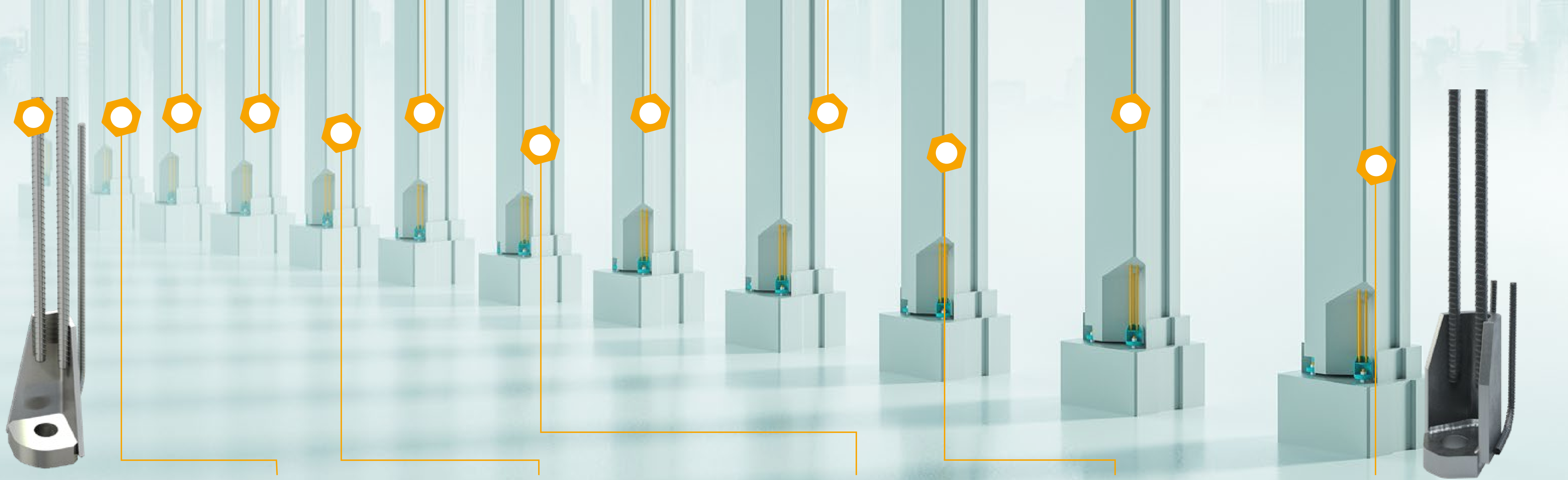
Today, Peikko operates in over 30 countries. The markets are growing constantly and new Peikko innovations are being introduced to meet the customer's needs. The most recent huge innovation for Peikko was launched this year, when BOLDA® Column Shoe was introduced. With its stronger design and elegant, more compact structure, it's the only ETA assessed column shoe for higher loads in the world. Peikko continues to define the game with a twinkle in the eye and as said – this is only the beginning.

A huge amount of product testing, with everything from concrete and fire testing to seismic testing, has been done in order to create the best possible products. Seismic tests in Italy.


In 2000, Peikko also entered the Spanish market, quickly gaining a credible market position. Los Pedroches Precast Factory - Jaén, Andalucía, Spain, 2005.

# 30 years of defining the game

## Steps of the Forerunner



**1991**
### Birth of the iconic HPKM®

HPKM® Column Shoes define the game. Peikko's revolutionary design uses bent high-strength steel in a welded box structure to create a smaller, lighter solution that is stronger and easier to use.

**1993**
### Peikko goes abroad

Peikko starts to market their new bolted column connection system abroad, beginning with the German market. At the same time, Peikko's resellers launch the system in Sweden and Norway.

**1995**
**PEC® for higher loads**

**2000**
**Peikko goes to Spain**

**2003**
### European Technical Assessment work begins

Peikko starts preparing for European Technical Assessment (ETA). This involves creating the standards for bolted column connections and developing standardized procedures to assess safe performance.

**2005**
**Peikko column shoes enter Russia**

**2009**
### First seismic projects in Turkey

Peikko Designer® software is launched. This is Peikko's largest single R&D investment. To make reliable, standardized designs easy, it includes ETA specifications and test results for Peikko's column shoes and anchor bolts.

**2010**
**Peikko pioneers ETA requirements**

**2011**
**Peikko enters China and APAC**

**2013**
### ETA is granted! Performance-based CE markings follow

The ETA documentation is ready and Peikko's bolted column connection system is the first to be granted an ETA. Peikko's column shoes and anchor bolts can now be CE marked to certify their performance.

**2017**
**The first seismic column shoe connection in the world**

**2021**
### BOLDA® Column Shoes are launched

Peikko launches their new and most advanced column shoe, BOLDA®. With its stronger design and elegant, more compact structure, Peikko defines the game again. It is the only ETA assessed column shoe for higher loads in the world.

Always seeking ways to offer

# More value in construction

The position of a forerunner must be earned over and over again.

Peikko was founded back in the sixties after a certain need arose on construction sites.

"That's how successful R&D starts every time – by identifying customer needs," says **Ján Bujňák**, who runs the Peikko Product Development team together with **Taru Leinonen**. Bujňák is responsible for development of precast and cast-in-situ connections, and Leinonen for development of the DELTABEAM® Composite Beams and Frames, design tools and Intellectual Property Rights.

According to an often-quoted story, **Henry Ford** would have been creating faster horses if he had simply listened to the market needs of his time.

"We want to avoid that and keep our minds open, but we still have to have a thorough understanding of what our customers' lives are all about."

However, there are realities that need to be taken into consideration.

"Not everything can be solved technically. Or the solution might not be commercially viable. We need to carefully choose which R&D battles we want to take part in and win," Bujňák stresses.

> By having a multicultural R&D team, we are able to understand the market differences better.

### INCREMENTAL STEPS OR LEAPS?

Peikko's customers often must concentrate on their core businesses, whether it's architecture, structural design or construction.

"But we, as a component and solution supplier, are in a position where we can put our time and energy into imagining and creating solutions that don't exist. Or in fine tuning the details of the current products so that they are better than before."

Ideation is the creative part of the process, where a lot of people like to be involved.

"You don't necessarily have to change the game totally with your every product launch," Ján Bujňák points out. "But of course, you can!"

If the new solution is 10% better compared to the old one, that's already a significant and value creating step forward.

The construction industry is heavily regulated.

But according to Bujňák, the field tests showcase not so much the technical quality of the product, but rather the practical value of it.

"Most of our proprietary, innovative solutions often fall out of the scope of the current standards. This is where we need approvals from the building authorities."

### OFFERING MARKET SPECIFIC PRODUCTS OR CHANGING THE MARKET?

Operating globally can be seen both as a challenge and an opportunity.

Quite a few of the Peikko innovations have been originally developed for the Finnish market, where Peikko has stood for speed, safety, and efficiency ever since the company was founded.

"We want to offer the same advantages in all the markets, but no other market is identical to Finland, so it would be foolish to offer exactly the same. We adjust our offering to suit local markets where needed. We also learn a lot in the process," Bujňák explains.

In addition to European R&D centres in Finland, Germany, Slovakia, and Lithuania, there are R&D functions also in China, Canada, Italy, and Latvia.

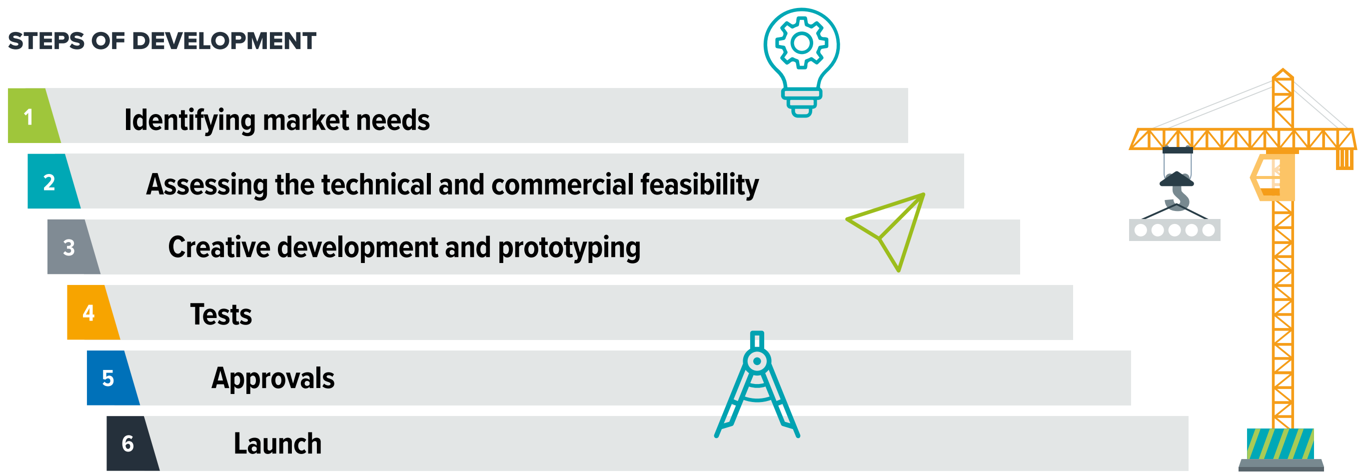
"By having a multicultural R&D team, we are able to understand the market differences better. And experts from different markets might have different ways of understanding the same problems. That brings up new ideas."

### SHARING WHAT WE KNOW

Peikko is committed to sharing the knowledge for the common good, be it technical papers, webinars, seminars, videos, or informal chats.

"We are always looking for ways to make the industry better – faster, safer, and more efficient. If you think of our founder **Jalo Paananen**, you can see that bringing up and sharing new ideas is in our DNA".

### STEPS OF DEVELOPMENT



# WILJA® Lifting Insert — Stainless steel lifting insert for sandwich elements

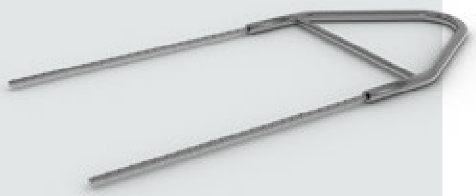
WILJA® Lifting Insert is designed for lifting and transporting precast sandwich wall elements. It is a CE marked, efficient, and ready-to-use solution made of stainless steel.

WILJA® Lifting Inserts have five different load classes and are available for several insulation thicknesses. WILJA® Lifting Inserts are permanently cast into the inner and outer panels of sandwich walls, and the anchoring is based on the inserts' own anchoring rebars. Using WILJA® requires no system specific lifting keys.

WILJA® Lifting Insert is an improved version of the PNLF Sandwich Wall Insert and it will replace the PNLF. It has been tested in concrete and against steel failure, and it complies with the state-of-the-art regulation Machinery Directive 2006/42/EC and VDI BV-BS 6205.

The improved design of WILJA® inserts together with the new instructions on handling challenging openings and narrow areas makes the insert selection easy.

This new product is available for Scandinavia and the Baltics.



# WILORA® Connecting Rail — Wire loop rail for wall connections

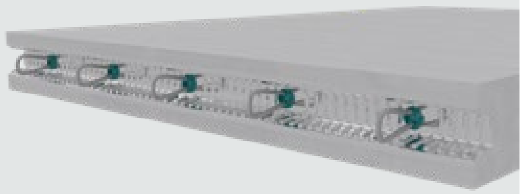
WILORA® Connecting Rail is a wire loop connection system for forming joints between precast wall-to-wall or wall- to-column connections.

Create a wall joint with a pair of WILORA® Connecting Rails, add the vertical rebar and grout – a fast and easy way to make a joint that is resistant to shear and tensile forces.

WILORA® Connecting Rails are manufactured from profiled steel rail with five wire loops inside that are protected by a deck. The rails are installed on the formwork at the full length of the joint, creating the casting channel without extra work. Enjoy the fast installation, improved accuracy of dimensions, and easy assembly to the formwork using nails and simple tools.

1250 mm long WILORA® Connecting Rails are available in two sizes: 50 mm high and 20 mm high. The option to use both thixotropic and normal grout makes the WILORA® Connecting Rail system suitable for a wide range of applications.

The WILORA® Connecting Rail has approval from the Concrete Association of Finland and is now available for Scandinavia and the Baltics.



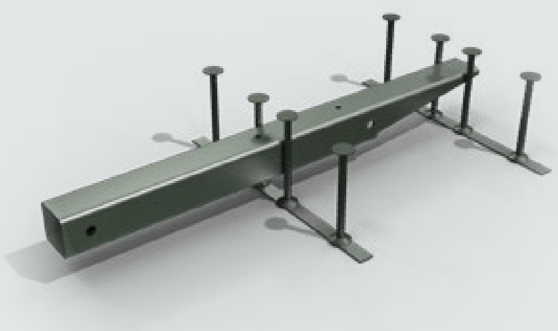
# SLADEX® Balcony Slab Connector – Precast slab support with stud reinforcement

SLADEX® Balcony Slab Connector creates an efficient connection between the precast balcony slab and load-bearing structure without compromising the thermal insulation on the sandwich wall panels or the building envelope.

It consists of a stainless steel RHS tube and rails with double-headed studs, and it is cast into the balcony slab at the precast factory.

SLADEX® Balcony Slab Connector can be used both in precast and cast-in-situ buildings, where supported precast balcony slabs are used. After assembling the slab at the construction site, it offers reliable load distribution to the surrounding load-bearing structures.

With four standard models and the approval of the Concrete Association of Finland, SLADEX® Balcony Slab Connector is now available for Scandinavia and the Baltics.



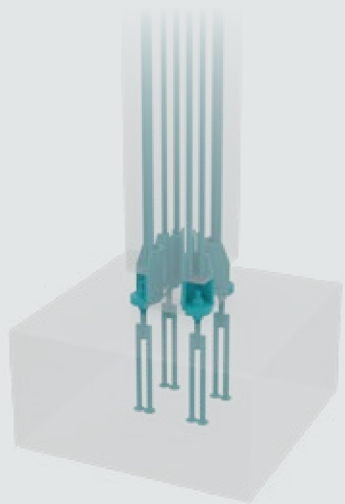
# BOLDA® Column Shoe — Strong and optimized bolted column connection

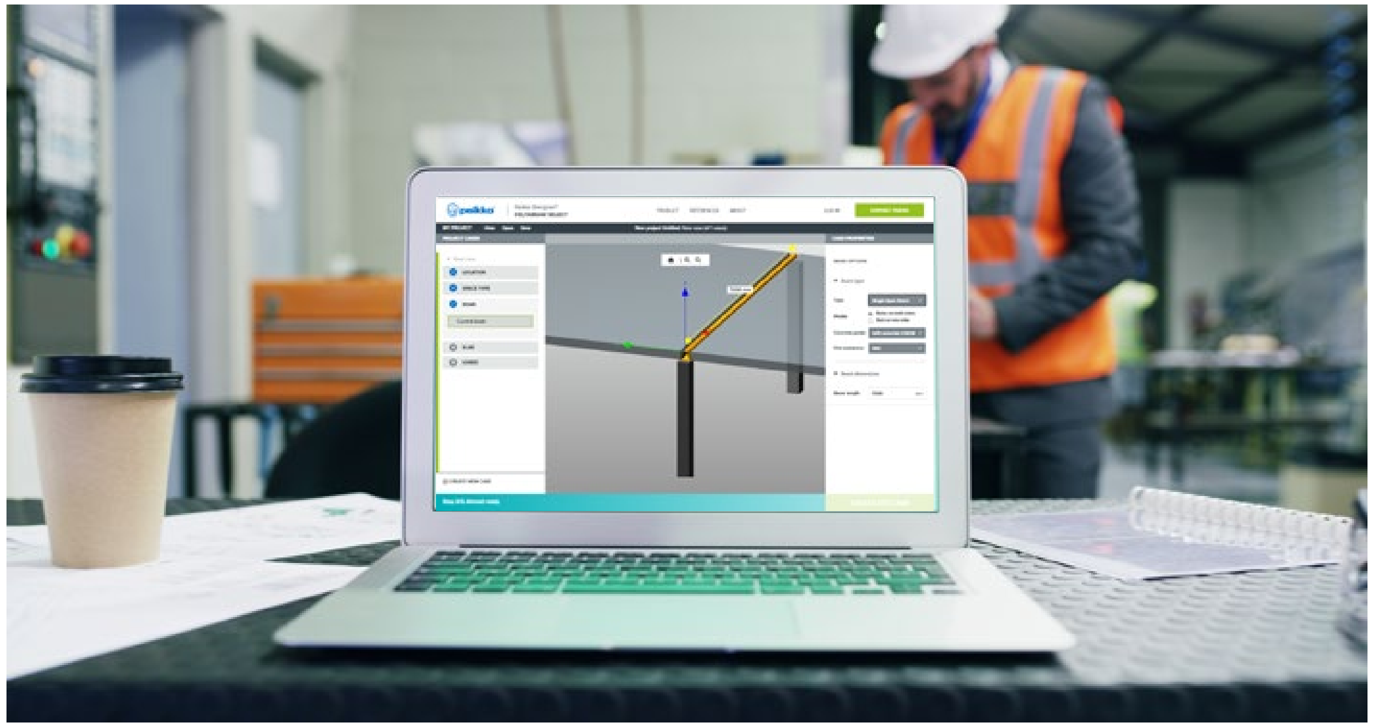
BOLDA® Column Shoes were designed and developed to introduce a new generation of column shoes. It is an efficient replacement for PEC® Column Shoes in heavy loading conditions.

BOLDA® Column Shoes are ETA assessed based on the full-scale tests of bolted column connections to prove the bending and shear resistance, stiffness, and resistance when the connection is exposed to fire.

BOLDA® Column Shoes are compact column shoes to fit in a smaller and narrower column cross-section. It is possible to reduce column cross-section up to 24% with BOLDA® when compared to PEC® Column Shoes. Thanks to its optimized design, it is easier to handle and install it in the precast factory.

All the benefits of a standard bolted column connection are of course applicable when BOLDA® Column Shoes are used. For example, no bracing is needed, which allows for a free working space where the connection is instantly secured when bolts are tightened. Erection of the precast column takes around 10 minutes with the use of a crane and only a two-man crew. Behaviour of the precast column and connection can be safely considered to be comparable to cast-in-situ structure.





# Making structural designers' work more effective

# A sneak peek on what is about to come

Since 2009, Peikko Designer® has been assisting structural designers in their work. It has come a long way since the first iterations.

Peikko has always been an innovative manufacturing company with products and solutions that have pushed the boundaries of on-site efficiency and ease of use.

"But in order to offer even more value for our customers and especially for the structural designers, we are investing heavily in software development and services," says **Anna Stirane**, Product Manager for Peikko Designer®.

According to Anna, the aim is to build tools that integrate fluently in engineers' workflow and enhance their productivity.

"One aspect of integration is that unnecessary and repetitive tasks are minimized. Thanks to this, less time is used for unproductive tasks such as filling in the design parameters again and again when you switch between design software and applications," Stirane states.

With software integration, engineers can concentrate on doing something that really matters and create value for their customers.

"A perfect example of integration is the project with A-Insinöörit, a Finnish construction engineering and consulting company."

Peikko provided DELTABEAM® Design Service where Peikko let external applications use Peikko's online resources through an API communication layer. As a result, DELTABEAM® design became connected with the engineering workflow within A-Insinöörit company.

"If you are interested in DELTABEAM® design integration with your own engineering platforms, don't hesitate to contact us," Stirane reminds.

## FOCUSING ON EASE OF USE

All Peikko Designer® applications and modules released after 2018 are cloud-based.

"The advantage is that you don't need to bother the IT department for installation and configuration, or worry about compatibility. Updates are automatic and the design tools can be used wherever you are. This has been another goal to make software more accessible," points out Stirane.

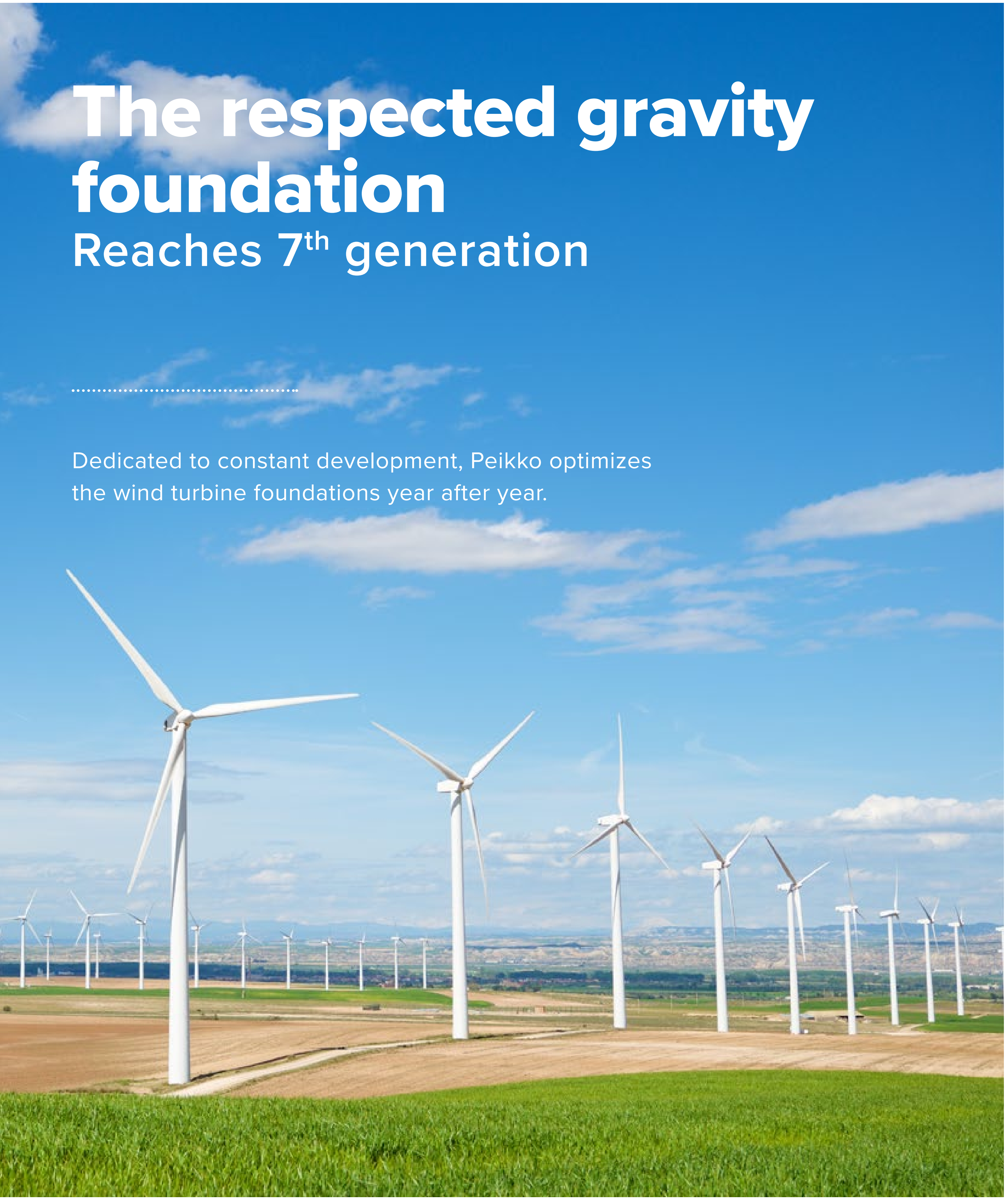
The designers are used to making do with less than perfect workflows.

"We focus on making the software as easy and intuitive as possible. Our aim is that using Peikko Designer® is always a delight, never a chore."

> **But in order to offer even more value for our customers and especially for the structural designers, we are investing heavily in software development and services.**

### THE NEXT MILESTONES

- We will continue to integrate DELTABEAM® Design Service into other FEA packages for structural analysis.
- Two new software applications – Application for the Design of Floor Joints in compliance with TR 34:4 and Application for the Design of Balconies with EBEA® Balcony Connectors – will be released in the early summer 2021.



# The respected gravity foundation

## Reaches 7th generation

Dedicated to constant development, Peikko optimizes the wind turbine foundations year after year.

Even though wind is generally seen as low carbon energy source, it has its emissions.

"We aim to systematically lower the emissions to make wind as green as possible," states **Antti Rousku**, Business Director for Peikko's wind energy applications.

A perfect example of this is the gravity foundation, which excels in a variety of geotechnical conditions. The loads are transferred from the tower to the ground through an anchor cage and its most visible feature – the wide and shallow base over a large area of soil.

"But this requires large volumes of concrete and reinforcing steel," Rousku points out.

If the material amounts can be reduced, the foundation will be easier and faster to build.

"And the price, and $CO_2$ emissions, will be lower."

### MAKING THE FOUNDATION MORE EFFICIENT, STEP BY STEP

The first designs and projects were completed between 2011 and 2013, but the respected gravity foundation has enjoyed several development phases ever since.

"In 2014, 3D modeling automatization was added to reduce the design, modeling, and production time for faster deliveries. The experience gained earlier allowed us to significantly improve the design," says Rousku.

This generation was well received on the Finnish and Swedish markets with 700 foundations delivered.

With the 5th generation in 2018, there was one of the most visible improvements.

"The shape of the slope changed from convex to straight. This helped us to reduce the amount of steel and concrete. As a result, the $CO_2$ emissions of the foundation were lowered substantially."

The 5th and 6th generation designs utilized Peikko's long PSB® Reinforcements to reduce the reinforcement density in the center part of the foundation. This made the foundation easier and faster to construct. It also made the fitting of the cable ducts through the foundation more straightforward.

"Simultaneously, we improved the PSB® shape to enhance its fatigue properties."

### UNVEILING GRAVITY7

The new Gravity7 has all the benefits of the earlier generations with some new extras added. For example, now the design is automatized and optimized with a full 3D FEM model.

"Now we can calculate the whole foundation more precisely as a single model and automatically optimize the reinforcements."

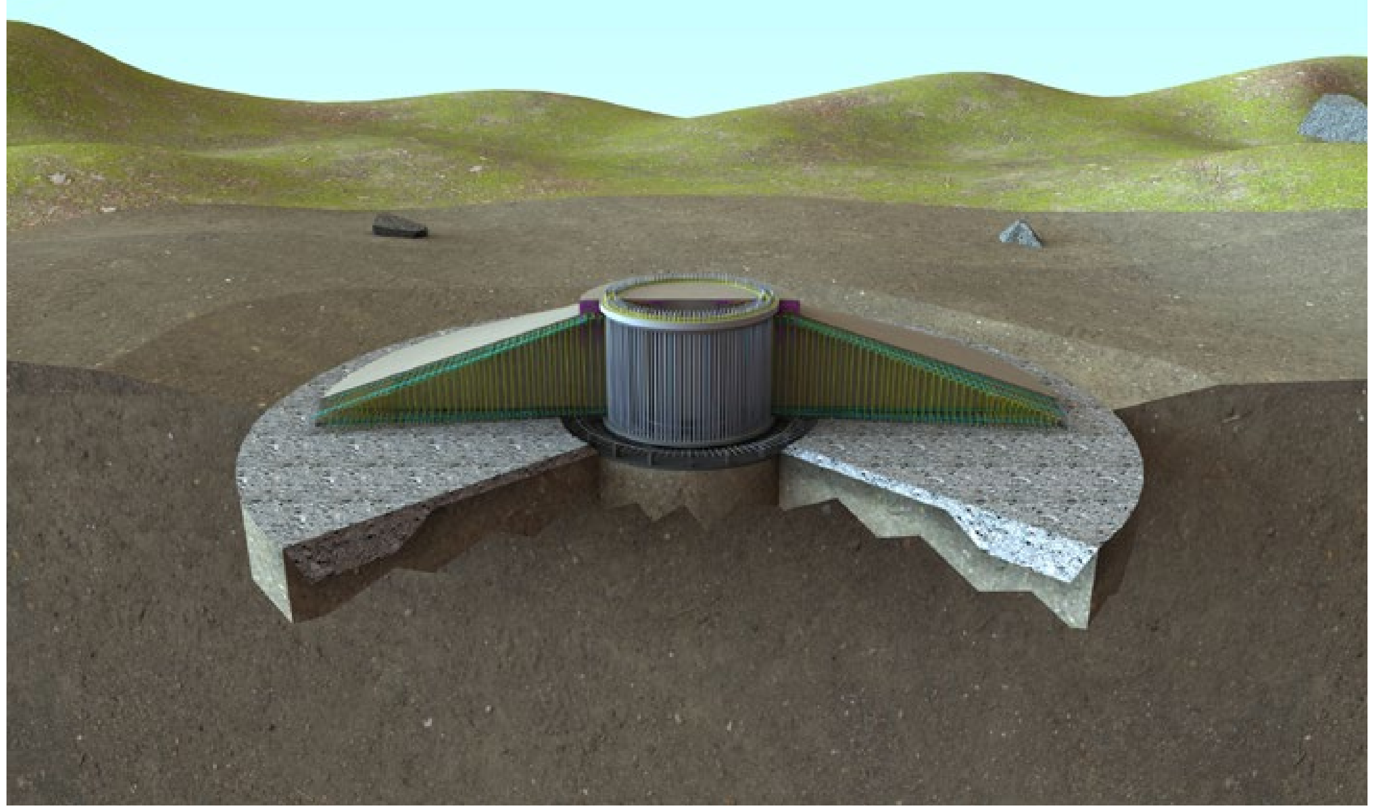
Non-linear FE soil simulation is another novelty.

"Thanks to that, we can use the actual soil properties to achieve even smaller foundations and use less materials," points out Rousku.

Gravity7 is the perfect choice for any project looking for the latest foundation technology.

> **We can use the actual soil properties to achieve even smaller foundations and use less materials.**

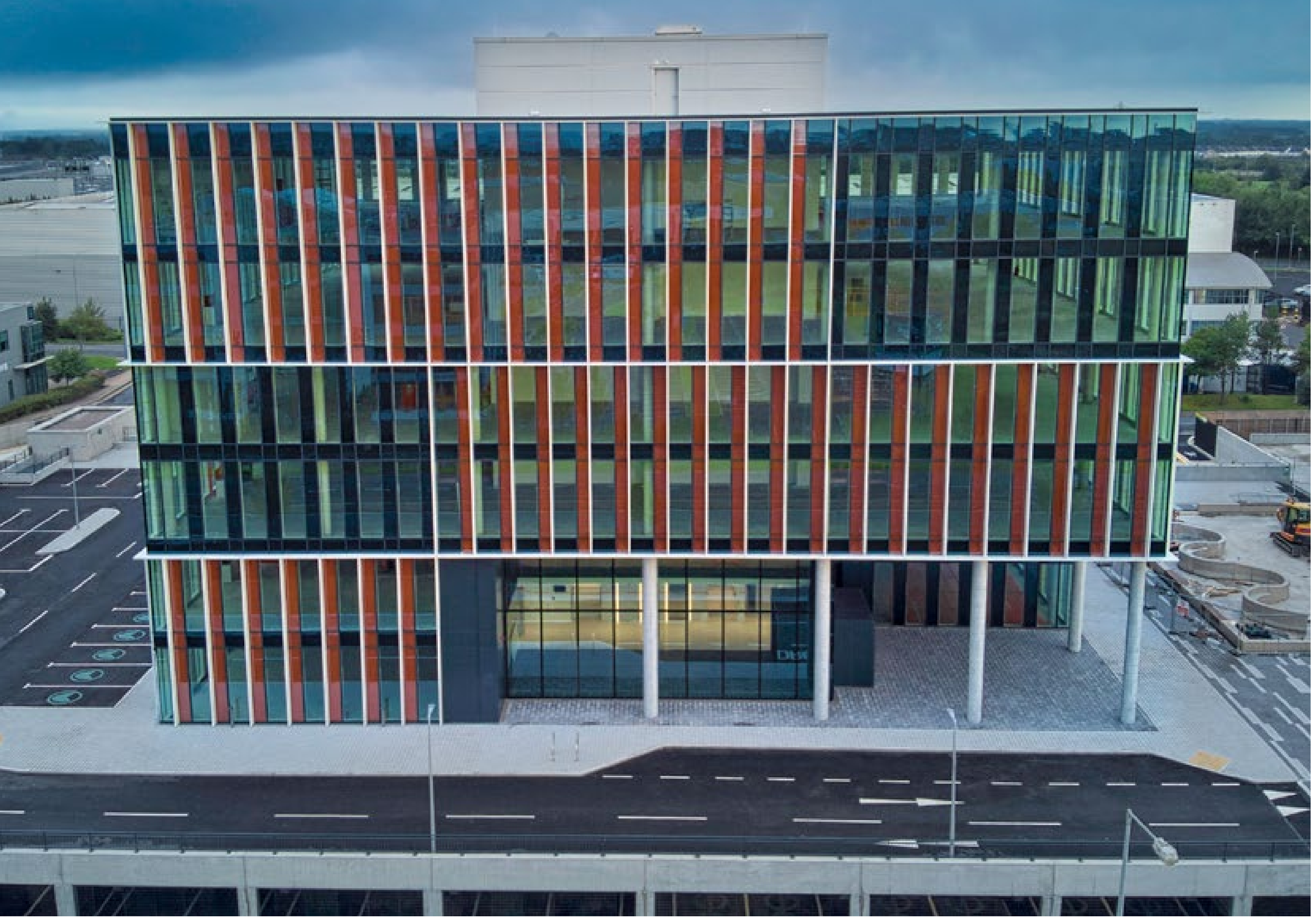
Gravity7 is the perfect choice for any project looking for the latest foundation technology.



# DELTABEAM® plays a key role

## in Dublin's new Stemple Exchange development

Peikko's DELTABEAM® has enabled the creation of minimal-column floorplans in two prestigious new office buildings in Blanchardstown Corporate Park, North West Dublin.



The six-story, 7,912 $m^2$ (9,463 sq yd) "1 Stemple Exchange" is complete and now leased by U.S. company Guidewire Software, and the identical "2 Stemple Exchange" is under construction. In this project, Peikko designed and supplied DELTABEAM® for the client O'Reilly Precast, working for the main contractor Bretland Construction.

The architecturally impressive, mirrored buildings were designed by TOT Architects, and have a high profile on the N2/N3 link road, which divides the 40-hectare corporate park.

Stemple Exchange's structural design uses precast square and circular columns, with the DELTABEAM® Composite Beams supporting prefabricated, prestressed, and relatively lightweight hollow-core slabs. Having DELTABEAM® spans as long as 12 meters (39 ft) reduced the number of columns required by four per floor.

Both buildings have U.S. Green Building Council LEED Gold certification (Leadership in Energy and Environmental Design). Their features include central cores that help to maximize natural light in the office areas, clean uninterrupted floor plates, spacious 2.8 m (9.2 ft) floor-to-ceiling height, 15 cm (0.6 in) raised access floors with power, double-glazed curtain walling, high-speed lifts, and a total of 500 car parking spaces.

### FLEXIBLE, OPEN FLOORSPACES

**Liam Murphy**, Regional Director at structural engineer Doherty Finegan Kelly, says: "On this project speed of construction was essential, which is why we chose DELTABEAM® over the originally designed flat slab solution. We minimized onsite wet trades using precast floor slabs with DELTABEAM®, which in turn minimized crane lifts, provided working platforms, and eliminated the need for back propping between floors. DELTABEAM® also gave us large, extremely efficient floor plates and removed the requirement for some internal columns, greatly increasing flexibility in our tenants' open-plan offices."

"We found Peikko to be thoroughly professional and have been particularly impressed by the level of detail in the working drawings produced, which has helped ensure the quality of the finished building."

According to **Mike Scott**, Peikko Sales Manager DELTABEAM®, potential clients are always impressed with DELTABEAM® product's fast, straightforward installation and many features, capabilities and benefits including long spans and integrated fireproofing. Mike Scott says: "Stemple Exchange is Peikko's largest project in Ireland to date, we're getting very positive feedback and it's opening the door to further projects."

**Seán Murphy,** Development Manager at Blanchardstown Corporate Park developer Channor, says: "Peikko DELTABEAM® has enabled us to achieve a flat slab soffit (critical for ceiling void services) while using the speed and efficiency of precast concrete construction. The superior spans achievable with DELTABEAM® have eliminated mid-point internal columns, thereby giving our tenants maximum flexibility with internal fit-out design."


### PEIKKO EXPANDS IN IRELAND

In Ireland Peikko has been supplying the precast and cast in-situ for several years. In 2018 DELTABEAM® was used in the Four Ferns Nursing Home project, working for O'Reilly Concrete and main contractor Purcell Construction.

"Everyone's very happy with Stemple Exchange," says **David Pike**, Managing Director for Peikko Ireland. "We're now speaking with more structural engineers to get DELTABEAM® specified, and we're speaking with the precast manufacturers and installers, and through them the main contractors and clients. We highlight major benefits such as efficient offsite construction, faster installation using fewer personnel, greater program certainty, reduced need for concrete, and fewer site vehicle movements."

# In China, bolted connection stands for Rigid and fast construction


Peikko's bolted connection has been defining the game for 30 years. Now it's being adopted within the Chinese market.

To communicate its virtues, the bolted connection was given a Chinese name.

"We call it Gangjie, which means both rigid and fast," says **Huafei Shi**, the Sales Director of Peikko China.

The name highlights the two basic properties of the bolted connection. According to Shi, the name is also very easy to pronounce and use for the locals.

Officially launched in 2019 at the biggest construction exhibition in China, Peikko and Gangjie are not the only players in the Chinese field of bolted precast construction.

"But our customers are starting to realize that Peikko is the original inventor of the bolted connection. That's why we are rightfully seen as forerunners when compared to the competitors."

As most of China is seismically active, the designers are very interested in seismic performance of the connection.

"The designers want to play it safe and use the original solution if they can. They like to rely on Peikko's expertise."

### SHIFTING FROM THE TRADITIONAL TO THE MODERN

The potential of the Gangjie system is huge, as currently 90% of all construction in China is labor-intensive and cast-in-situ.

"But the strategy of the Chinese central government calls for a shift from traditional cast-in-situ technologies to more advanced precast."

Surprisingly, the shortage of skilled workforce is one of the reasons for the paradigm shift.

"Young people no longer want to work in construction, they are drawn to other industries such as IT and logistics. You see a lot of women and older men on building sites, so you need to come up with something that's more efficient than the traditional building methods," Shi explains.

He also points out that controlling the quality is often an issue with the competing connection methods.

"Chinese are focused on the speed of building, but then it's easy to compromise quality. With the Gangjie – our bolted connections – both the quality and speed of construction can be kept high."

### BEWARE OF THE COPYCATS

The designers are constantly looking for new, innovative building methods.

"But they are also somewhat suspicious by nature. They need more local references."

Shi says that many local competitors in China are great in copying.

"The government encourages and funds innovation, but luckily also the IP rights are enforced. We are doing all we can to help the authorities, designers and contractors to get in speed with the bolted connections."

Local standards for bolted connections were created in early 2020.

"Since then, Gangjie has been used with three reference cases – petrochemical and electronics factories, as well as an office building. And there's more to come."

In 2021, Peikko China is looking forward to executing projects in the pharmaceutical and other high-end industries.

"These are great opportunities for us, as each segment has its own, specific requirements," Huafei Shi concludes.

# Innovative solutions allow for **Continued production during factory expansion**

Continental Brands is adding 7,000 $m^2$ (8,400 sq yd) to its Johannesburg-based factory over two phases, providing additional production, storage, and office space.

Production was not interrupted at South African biscuit producer when Peikko solutions were used to convert two ground-floor factory/warehouse buildings into multi-level structures.

Phase 1 took place in 2020 and added a 2,000 $m^2$ (2,400 sq yd) second level above the ground-floor factory (Block A). Phase 2 will see the addition of two floors to an adjacent warehouse (Block B) and the construction of a new building on an open ground situated between Blocks A and B. The open-ground building is being attached to the extended Block B to form a seamless three-story structure.

Both extension phases were designed by **Marco Riccardi** Architectural Design.

According to Riccardi, the expansion will enable the doubling of output from two to four production lines and will provide for any future expansion of production and storage space.

“Speed of erection, column strength and the use of as few columns as possible were some of the elements that informed our decision-making process. But the fact that the production could continue during construction, was the clincher.”

The project involved using precast concrete columns and hollow-core slabs in combination with anchor bolts, column shoes, DELTABEAM® Composite Beams, hidden corbels, and COPRA® Anchoring Couplers.


“We prepared a 3D model so that the client could see the precise column placement. We then drew up a detailed engineering plan, which included column design and the placement of rebar, column shoes, and the levels of the hidden corbels,” said Peikko's Project Engineer **Winston Visser.**

The extension of Block B began by cutting the surface bed of the existing ground floor and casting mini-pile caps with anchor bolts.

“12-meter-high columns were lowered through the roof onto the mini-pile caps. Steel nuts were then screwed onto the anchor bolts to hold the columns securely in their position. The installation and securing of the columns only took a day,” advised Visser.

Once the ground-floor columns had been installed, construction of the second floor began. The second floor was constructed before the first floor so that when the existing steel roof of the ground floor unit was removed, the ground floor would not be left at the mercy of the elements. DELTABEAM® beams were attached to anchor bolts on top of the 12 m (39 ft) columns and hollow-core slabs were laid on the DELTABEAM® beams. The former process was completed in the morning and the latter in the afternoon. The hollow-core beams were covered with a reinforced in-situ structural topping.

The steel roof of the ground floor building was then removed, and the construction of the first floor started. It followed a similar process to the construction of the second floor with the exception that the DELTABEAM® beams were attached using hidden corbels inserted inside the 12 m (39 ft) columns.

The next phase involved installing twenty-two 7.5 m (25 ft) perimeter columns on top of the 12 m (39 ft) columns using anchor bolts and column shoes. These columns, plus a 9.5 m (31 ft) column attached to a DELTABEAM® in the middle of Block B’s second floor, were used for roof support. The new roof was connected to the columns using Peikko’s COPRA® Anchoring Couplers.

“The Peikko system is transforming the South African construction landscape,” said Riccardo. “We have several international clients who are moving in this direction. Besides being a timesaver, it complies with South Africa’s health and safety requirements.”


## PROJECT FACTS

- DEVELOPER: CONTINENTAL BRANDS
- ARCHITECT: MARCO RICCARDI ARCHITECTURAL DESIGN
- STRUCTURAL DESIGNER: MR. SPIROS SDRALIS PR.ENG. (PDS)
- CONTRACTOR: LUDIKON CONSTRUCTION & CSS CONCRETE SLAB SUPPLIES

# Punching reinforcement system for pile-supported slabs

# Speeds up infrastructure construction and increases efficiency


The Kirismäki interchange, which is a part of the E18 Turku ring road improvement project, is a pilot site where Peikko's PSB® Punching Reinforcement System was used for the first time in a road's pile-supported slab structure to strengthen the connection points of foundation piles and concrete slab.

Road network and the related intersection construction projects are often huge in size, and their construction may take years. That is why technical solutions that speed up the construction and improve cost-efficiency are very welcome.

In Finland, the European road E18 goes through the whole of Southern Finland, in the east from the vicinity of the Russian border to Turku on the west coast of Finland. On the ring road passing Turku, traffic flow will be improved when one section of the road is constructed to have four lanes in Finnish Transport Infrastructure Agency's road improvement project. At-grade intersections will be eliminated and replaced by an overbridge at Kirismäki interchange improvement.

### NEW SOLUTIONS FOR THE NEEDS OF INFRASTRUCTURE CONSTRUCTION

Peikko proposed a totally new kind of a solution for the pile-supported slab to the Finnish Transport Infrastructure Agency. The starting point was to establish how the ETA approved PSB® Punching Reinforcement System, which has long been used in building construction, could simplify the strengthening of the roadbed's pile-supported slab.

After preparing the design criteria, a trial use permit was received for the structure, and the Kirismäki interchange was selected as the pilot site. The solution was implemented together with the Finnish Transport Infrastructure Agency, WSP Finland, who were responsible for designing the pile-supported slab structure, and Destia as the main contractor.

"Peikko wants to be a significant supplier of fastening and connection technology for infrastructure projects. New innovations are sought, both by applying solutions that are familiar in building construction, as well as by developing completely new solutions. The development work is most fruitful when it is performed in close cooperation between the developer, designers, and constructors," says **Topi Laiho**, Business Manager for Peikko's infrastructure construction.

### THE PILE-SUPPORTED SLAB WAS STRENGTHENED WITH PUNCHING REINFORCEMENT

At sites that require pile-driving of the roadbed, the pile-supported slab is usually implemented as a so-called mushroom slab structure. In it, the connections between the piles and the slab are strengthened using a concrete bulge, which is cast on the upper part of the pile and which, together with the pile, strengthens the concrete slab cast on top of it.

The functioning of Peikko's PSB® Punching Reinforcement System is based on the excellent anchoring characteristics of the product. Reinforcement rails form a star-like structure inside the concrete slab. It is fastened with thin binding wires into the slab's concrete reinforcement above each pile.

> **The punching reinforcement system speeds up the construction of a pile-supported slab significantly.**

The advantage of this solution compared with a mushroom slab structure is speed. Construction can be implemented directly to the level ground. Thus, there is no need to mold holes needed for casting concrete reinforcement around the piles, which significantly shortens construction time.

### COSTS OF THE SOLUTION ARE OPTIMIZED IN THE DESIGN PHASE

WSP Finland's designer and Project Engineer **Jaakko Ingerttilä** says that the design of a pile-supported slab requires multidimensional optimization. The aim is to achieve the best possible cost-efficiency. In the design, for example the type and bearing capacity of the soil, as well as the load and elevation of the road structure, are taken into consideration. These factors have an impact on the selection of the pile type and on the positioning of the piles beneath the slab. In addition, the property class of the concrete in the slab, slab depth and reinforcement are optimized.

→

### DESIGN OF THE PILE-SUPPORTED SLAB FOR THE KIRISMÄKI INTERCHANGE

In the Kirismäki project, reinforced concrete piles were used. Because of the thick clay soil, the aim was to minimize the number of piles. When there are fewer piles, a great force of the pile load is impacted on the connection of the pile-supported slab, and the pile tends to punch through the slab. It is possible to increase the slab's punching resistance by making the slab thicker, using shear reinforcements, or by changing the concrete strength.

In the pilot project, one section of one pile-supported slab was implemented using the PSB® Punching Reinforcement System instead of a mushroom slab. This was the first time that this Peikko's System was used in a pile-supported slab project. Peikko provided design support as well as guidance in the use of the Peikko Designer® software.

"Together with the Finnish Transport Infrastructure Agency, Peikko has performed good work with the design criteria," Jaakko Ingerttilä mentions.

"The punching reinforcement dimensioning methods that are in use in Finland are based on the Finnish building regulations, whereas the dimensioning of the PSB® Punching Reinforcement System is based on Eurocode and the ETA assessment of the product. There are slight differences between these and for this reason, my understanding is that with Peikko's PSB®, it is not possible to achieve slabs as thin as might be possible. We have presented Peikko with a development idea in this area."


### DESTIA COMPARES THE BENEFITS OF PILE-SUPPORTED SLAB STRUCTURES

In the Kirismäki interchange, both the traditional mushroom slab and Peikko's PSB® System were used to compare the functioning and cost impacts of the solutions. At Destia, the comparison of the pile-supported slab structures is performed by **Panu Salminen**, foreman:

"The punching reinforcement system speeds up the construction of a pile-supported slab significantly, because one work phase, namely the holes made for the mushroom structures and concreting these, is eliminated. This can speed up the work by up to a week." Installation of the punching reinforcement was really easy and fast according to Panu Salminen.

The use of the punching reinforcement system does, however, require a thicker concrete slab. In these types of projects, the depth of a mushroom slab's concrete slab is usually 25 cm (10 in) and at the mushroom bulges, 53 cm (21 in). In the case of Kirismäki punching reinforcement system, the slab depth was 41 cm (16 in). On the basis of the pilot project's comparison calculations, design criteria for reducing the slab depth can be reassessed. ●

PROJECT FACTS

- DEVELOPER: FINNISH TRANSPORT INFRASTRUCTURE AGENCY
- STRUCTURAL DESIGNER: WSP FINLAND OY
- MAIN CONTRACTOR: DESTIA OY





# Company news in brief

## Peikko purchased new factory premises in Lithuania

Peikko has purchased factory premises of 25,000 $m^2$ (30,000 sq yd) in Kaunas, Lithuania, located very near to its existing factory premises.

First, Peikko increases the manufacturing capacity of EBEA® Balcony Connectors, where Peikko Lithuania has a role to deliver this product line particularly for the North European market. Secondly, Peikko increases the production capacity of ATLANT® Composite Columns, a column system providing slimmer and more architectural structures.

The new premises in Lithuania not only provide Peikko with a solid foundation to continue growing in the Nordic markets, but also offering customers top-class solutions manufactured close to the market.


## Peikko started manufacturing in Turkey

Peikko has started manufacturing in a newly established premises in the city of Izmit, near Istanbul. Peikko has had its own Sales and Engineering team in Turkey since 2009.

To be able to serve our Turkish customers and grow the business further in the environment of fluctuating currency exchange rates, increasing logistics costs, and the existence of customs duties, it is imperative to have a more local approach.

The first manufactured products are related to industrial flooring solutions, such as customized TERAJOINT® floor joints. The intent is to expand the product offering and scale of operations rapidly in the years to come.


## French ATEx approval received for Peikko's DELTABEAM®

Peikko has received ATEx (Appréciation Technique d'Expérimentation), an approval for its DELTABEAM® composite beam from CSTB, the French Scientific and Technical Center for Buildings.

ATEx is a favorable, official expert opinion for the use of the DELTABEAM® product by the French authorities, and it simplifies the use of the product, as with this documentation, the construction project control authorities accept the use of DELTABEAM® without delay and further questions.

The new approval opens up great business opportunities for the coming years for Peikko's DELTABEAM®. ATEx is a major industrial milestone, since it facilitates the entry of slim-floor technology systems into France, and supports the use of hollow-core slabs.

# Minimizing thermal bridges in balconies

In the near future, life will be enjoyed on the balconies of Trelasttunet.

This time, EBEA® project greetings from Norway – and there is more to come.

Trelasttunet is located south of Stavanger, in the village of Nærbø. Consisting of three separate sections, the four-story high Trelasttunet C houses 17 quality apartments from 72 m² (86 sq yd) to almost 160 m² (190 sq yd). Life on the outside being one of the main features of the building, a total of 21 balcony elements are shared between 12 apartments.

"The delivery was carried out as agreed. The product was good and changes along the way were done swiftly. We are very satisfied," says **Edvin Ueland** of Jærentreprenør AS.

EBEA® Balcony Connector is a cost-efficient and practical solution for creating load bearing structures with minimized thermal bridges. In a cold climate like Norway, that's an absolute requirement.

"Thanks to its special materials, EBEA® also allows for achieving noise reduction at up to 21 dB and fire protection classification of up to REI 120. It can also be used on other applications such as walls and slabs," points out **Mattis Raaholt** from Peikko Norge AS.

The delivery consisted of 69 pieces of EBEA® Balcony Connectors.


## PROJECT FACTS

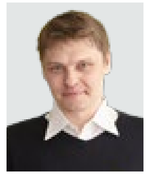
- DEVELOPER: BRYNELUNDEN AS
- ARCHITECT: SJO FASTING ARKITEKTER
- STRUCTURAL DESIGNER: BOYE OG WAAGE & CO AS
- CONTRACTOR: JÆRENTREPRENØR AS



PEIKKO
WHITE PAPER


## BOLTED CONNECTIONS FOR PRECAST STRUCTURES

ENABLING CIRCULARITY WITHOUT COMPROMISING PERFORMANCE



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M.Sc.
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Precast construction offers numerous benefits to different stakeholders of the value chain in the construction industry. Precast elements are usually manufactured under controlled factory conditions, thus allowing the production of high quality and precision.

FIGURE 1 HPKM® COLUMN SHOES BEFORE AND AFTER CASTING OF THE PRECAST COLUMN

**PEIKKO BOLTED CONNECTIONS** provide fast and safe assemblies of precast concrete elements further improving the competitiveness of the precast concrete industry (see **figure 1**).

HPKM® Column Shoes, combined with HPM® Anchor Bolts or COPRA® Anchoring Couplers, are used to quickly create moment resisting column connections (see **figure 2**). Column shoes are cast into precast concrete columns, whereas anchor bolts are cast into foundations or other supporting structures. At construction sites, the columns are erected on the anchor bolts and adjusted to the desired position by tightening nuts onto the anchor bolts. After installation, the joint between the column and the foundation is grouted. At the final stage, the grouted joint acts as a traditional reinforced concrete section.

FIGURE 2 HPM® ANCHOR BOLTS AND COPRA® ANCHORING COUPLERS

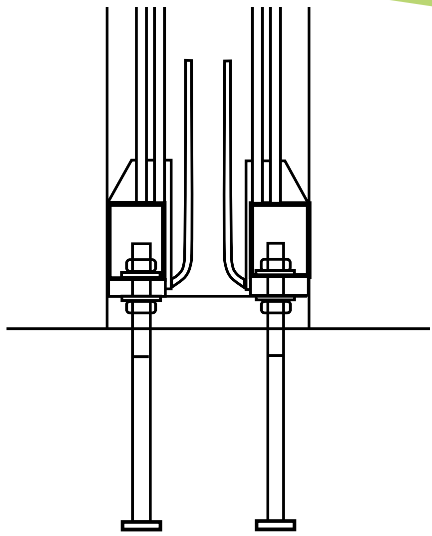

FIGURE 3 BOLTED PRECAST COLUMN CONNECTION WITH HIGHLIGHTED RECESS BOXES

The column shoes do not require any temporary bracing during the erection stage. Typically, four column shoes are enough to create a moment resisting connection (see **figure 3**).

**CHASING THE CIRCULARITY** of construction products and buildings is Peikko's passion and ambition.

While concrete is the most widely used construction material, it is also one of the biggest consumers of raw materials on our planet: 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 [1]. Additionally, the concrete industry has a significant influence on $CO_2$ emissions, and it consumes a great deal of energy every year. Producing one cubic meter of concrete using Portland cement and clinker results in emitting approximately 0.2 t of $CO_2$. About one ton of $CO_2$ is generated for each ton of clinker [2].

In addition to consumption of raw materials and energy, as well as high $CO_2$ emissions, over 11 billion tons of waste is generated due to demolition and construction work [1]. About 50% of this quantity comes from concrete waste [3]. Considerable amount of concrete structures around the world end their service life due to demolition, while they still possess some residual value and could serve much longer. Very few attempts have been made to reuse concrete structures of buildings ending their service life, even though studies have shown that by doing this, significant environmental benefits and energy savings could be achieved [2].

Lack of adaptability of connections between concrete structures is known as one of the biggest reasons that hinder reuse of precast concrete elements. In order to improve the reusability in new concrete buildings, connections should be designed to allow easy and cost efficient dismount [4]. The ecology of concrete structures could be significantly improved by applying the Design for Disassembly (DfD) in the design of connections. These facts have been acknowledged by the European Commission as some of the cornerstones of the Circular Economy Action Plan [5] that defines a roadmap for achieving the carbon neutrality of the construction industry within 2050. Among other issues, the Action plan implies that new material recovery targets will be set in EU legislation for construction and demolition waste in foreseeable future.

There are many types of concrete buildings that could already benefit from demountable connections, which would make it possible to dismantle and to reuse the structures. Secondary class buildings, like industry frames, warehouses, car parks, etc. might only be needed temporarily at certain locations. After the required service life, such buildings could be relocated to serve again wherever needed. In addition to relocation, removable structures could be also replaced if they are damaged or deteriorated.

Bolted connections have great potential to be the basis for the DfD and to increase the reusability of precast concrete structures [6]. In principle, untightening of a bolted connection should be as easy as tightening it.

### ARE PEIKKO BOLTED CONNECTIONS DEMOUNTABLE?

A series of experimental demonstrations have been organized by Peikko in order to answer the above question. First, precast columns were assembled and disassembled from a foundation on site. Thereafter, identical columns were supplied to a testing laboratory in order to investigate how the dismount ability effects their load bearing behavior.

→

### DISASSEMBLY TESTS

The disassembly tests were arranged by first casting three foundation blocks to the ground, 0.5 m x 0.5 m x 0.5 m in size. While one of the blocks was equipped with HPM® 16 L Anchor Bolts, the other two blocks were equipped with COPRA® 16 H Anchoring Couplers and M16 Threaded Bars (see **figure 4**).

In the second phase, precast columns (0.35 m x 0.35 m x 1.5 m), equipped with corresponding HPKM® 16 Column Shoes, were installed on the foundations (see **figure 5**) and the gaps between parts were eventually grouted with Fescon's JB 600/3, which is commonly used cement based mortar in Finland, generating the compressive strength up to 60 MPa.

A couple of weeks later, the dismount was executed by opening the upper nuts of anchor bolts / threaded bars and lifting the precast columns up using a mobile crane. After the dismount of the columns, the hardened grout blocks were removed quickly and easily. The adhesive bond between the grout and the structures was easily broken, and the grout got separated cleanly from the precast columns and the foundation blocks (see **figure 6** and **7**).

FIGURE 4 FOUNDATION WITH HPM® ANCHOR BOLTS FURTHER BACK AND FOUNDATION WITH COPRA® ANCHORING COUPLERS IN THE FOREFRONT

FIGURE 5 PRECAST COLUMN INSTALLED ON A FOUNDATION WITH TIMBER FORMWORK

FIGURE 6 REMOVED GROUT PAD AND EXPOSED FOUNDATION WITH COPRA® ANCHORING COUPLERS

FIGURE 7 SURFACE OF THE GROUT PAD WITH REMOVED COLUMN. CONNECTION WITH THE USE OF HPM® ANCHOR BOLTS

When removing the grout from the connections including COPRA® Anchoring Couplers, it was found out that the threaded bars could actually be screwed out from concrete and there was no need for any saw cutting (see **figure 8**). Also, HPM® Anchor Bolts were cleared relatively easily from grout, but removal of the grout had to be done by saw cutting, which demanded more time and effort (see **figure 9**).

In the last phase, the dismantled precast columns were reinstalled on the cleaned foundations and reformed connections were grouted again. This proved the reusability of both precast columns and foundation blocks (see **figure 10**).

FIGURE 8 M16 THREADED BARS OF COPRA® ANCHORING COUPLERS ARE BEING UNSCREWED

FIGURE 9 GROUT PAD REMOVED BY SAW CUTTING FROM THE FOUNDATION WITH HPM® ANCHOR BOLTS

FIGURE 10 REASSEMBLED PRECAST COLUMNS

## LOAD BEARING TESTS

In the load bearing shear tests, the columns were bolted to massive foundation parts (0.45 m x 0.7 m x 1.4 m). Like in disassembly tests, the joint gaps between the foundations and the columns were grouted with JB 600/3 cement based mortar, and the recess boxes of column shoes were left exposed (see **figure 3**). Two foundation blocks were otherwise identical, but while one of them used HPM® 16 L Anchor Bolts, the other was equipped with COPRA® 16 H Anchoring Couplers (see **figure 11**).

In the setup, the foundation blocks laid on strong floor and the other ends of the precast columns were supported on a hinged bearing. The applied force acted in vertical direction on the edge column end and was introduced by a hydraulic jack. Principle drawing about the test setups is presented in **figure 12**.

A steel spreader beam was used between the jack and the column end. Load was first elevated a few times to about 30 kN, and then degraded back to zero, before loading to the failure. These service load cycles caused a setting of the structure due to initial deformation. Photo from one of the test setups is presented in **figure 13**.

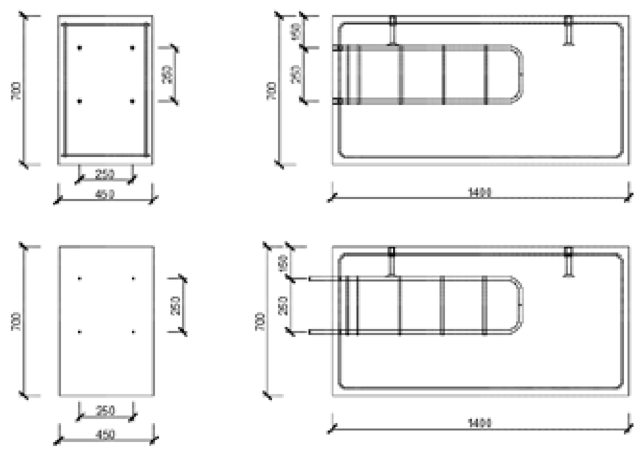

FIGURE 11 SCHEMATIC PRESENTATION OF THE FOUNDATION BLOCKS

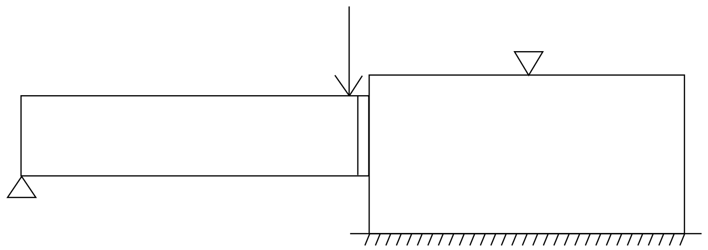

FIGURE 12 SCHEMATIC PRESENTATION OF TEST SETUPS

FIGURE 13 PHOTO FROM THE TEST SETUP, BEFORE LOADING THE CONNECTION

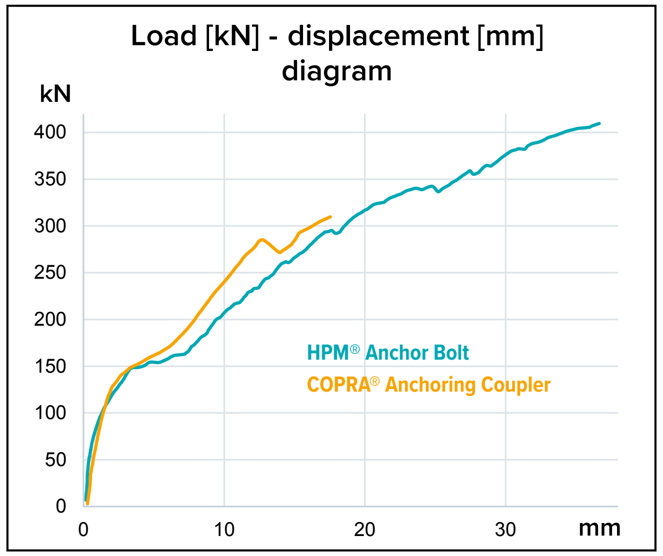


FIGURE 14 FORCE - DISPLACEMENT RELATIONSHIP

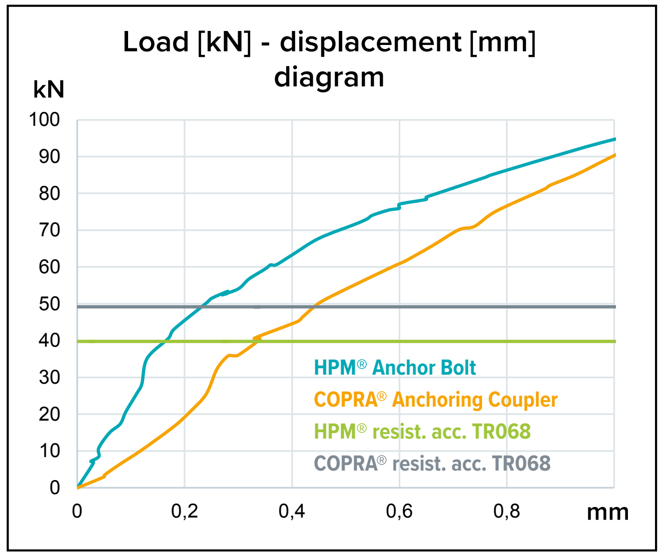


FIGURE 15 FORCE – DISPLACEMENT RELATIONSHIP, RANGE 0–1.0 MM

In addition to failure load, vertical displacements of the column ends were measured during the loading as shown in **figure 14**.

The behavior of both bolted connections followed a similar pattern. At first, a rigid behavior (shear deformation less than 1 mm) of the assembly was observed up to a load level corresponding to roughly 100–150 kN. Thereafter, deformations started to increase until the failure of the bolts that was associated with large shear deformations (more than 15 mm).

In practice, the shear design of bolted connections is based on elastic theory and only small deformations of the joint can be accepted even at Ultimate Limit State. **Figure 15** compares the load displacement curves of the both tested specimen under small displacements (0–1 mm). No significant difference between the performacne of a traditional connection and the connection with COPRA® Anchoring Couplers can be observed. The load level that can be sustained by the connections at a deformation of 1 mm is significantly higher than the theoretical design values of shear resistance (see **figure 15**), determined in accordance with Technical Report 068 of European Organization for Technical Assessment [7].

## CONCLUSIONS

The experiments presented here allowed us to demonstrate that bolted connections using both HPM® Anchor Bolts and COPRA® Anchoring Couplers are to some degree demountable. Still, the connection made using COPRA® Anchoring Couplers and Threaded Bars is reused more easily than the connection made using HPM® Anchor Bolts (possible damage of the thread during disassembly). No significant difference in the load bearing performance of both tested connections has been observed. The design following the principles of EOTA TR068 is conservative for both tested assemblies. Both connections presented ductile and robust behavior; the ultimate load associated with large deformations.

The output from the tests serves as an example of how Peikko bolted connections could be used to unlock the potential of precast concrete and to make the construction industry more sustainable and circular. Even if bolted connections make it possible to reuse of the precast columns and foundations, it should always be validated by the supplier or a third party.

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# Brand new Peikko book:

## “Double-headed anchors as punching shear reinforcement”


AUTHOR:
**Thomas Sippel**
Dr.-Ing.
Codes and Approvals Director
Peikko Group Corporation

Double-headed anchors, such as PSB®, are one of the most efficient systems for the reinforcement of concrete flat slabs against failure by punching.

The anchors are the most typically used to reinforce floor slabs, foundation slabs or column footings. This reinforcement technique has become almost a standard in Central Europe over the past 20 years; nowadays, it is becoming increasingly popular outside of Europe as well. The intention of the Peikko book “Double headed anchors as punching shear reinforcement - Explanations and guidance on design and construction” is to provide a solid technical package of information on the punching shear reinforcement. The book has been made as a dual language edition in English and German.

With the design method according to EN 1992-1-1, the favorable effect of the deformation-reduced anchoring of double-headed anchors compared to punching reinforcement made of stirrups cannot be assessed. Since the end of 2012, the first European Technical Approvals (ETAs) are available based on the same design concept developed for an application in conjunction with EN 1992-1-1.

With the conversion of the European Technical Approvals into European Technical Assessments, the design rules contained therein were also removed. This was taken as an opportunity to summarize the design concept with additional planning and design notes as well as design examples in the present book. Updated design rules for fatigue resistance are also incorporated. The book is intended to offer planners, engineers, and contractors guidance in daily practice.

PSB® and PSB PLUS® Punching Reinforcement fulfils all requirements regarding mechanical, fire, and corrosion resistance. Design of PSB® Punching Reinforcement is included in Peikko Designer® to facilitate daily tasks of structural engineers.

**You can order your book here:**



PEIKKO
# WHITE PAPER

# COMPOSITE COLUMNS
# CORBEL DESIGN VERIFIED

AUTHOR:
**Jaakko Soivio**
B.Sc.
R&D Engineer
Peikko Group Corporation

DELTABEAM® FRAME

The DELTABEAM® Frame is a steel concrete composite frame solution which consists of DELTABEAM® Composite Beams, Composite Columns, and connections between the structural members. Most often other steel structures such as bracing systems are included in the delivery. Although the design process is utilizing a standardized selection of components, each structural member and connection detail of the DELTABEAM® Frame is tailored to suit the project in question.

## BEAM TO COLUMN JOINTS

The flexibility and precision of the prefabricated steel components of the DELTABEAM® Frame allows for freedom in the architectural design. The variety of the shapes of frames sets high requirements for the joints between the structural members. The joints must not only fulfill the requirements of different design stages, but also be safe and easy to install.

The most common beam to column connection is nominally pinned. The definitive property of a beam to column connection varies from the construction stage to another, and from loading situation to another. From the load transfer point of view, the torsion resistance is a typically desired property in the construction stage, robustness in the accidental situation, and delayed temperature development in the fire situation respectively. For the normal stage, the design is principally defined by the vertical shear initiated by the support reaction from the beam. The vertical actions along a continuous column are transferred from the beam to the column by a variety of corbel arrangements. The load transfer to the composite section of the column is depending on the type of the corbel and possible shear devices.

## EUROCODES AND LITERATURE

According to Eurocodes [1] in the regions of load introduction a clear load path should be defined. The amount of slip required to reach the defined load transfer should not be in contradiction with the design assumptions. In the case where the load is at first introduced to the steel section and then further to the composite section, the shear stresses should be evaluated from the sectional forces by elastic or plastic analysis.

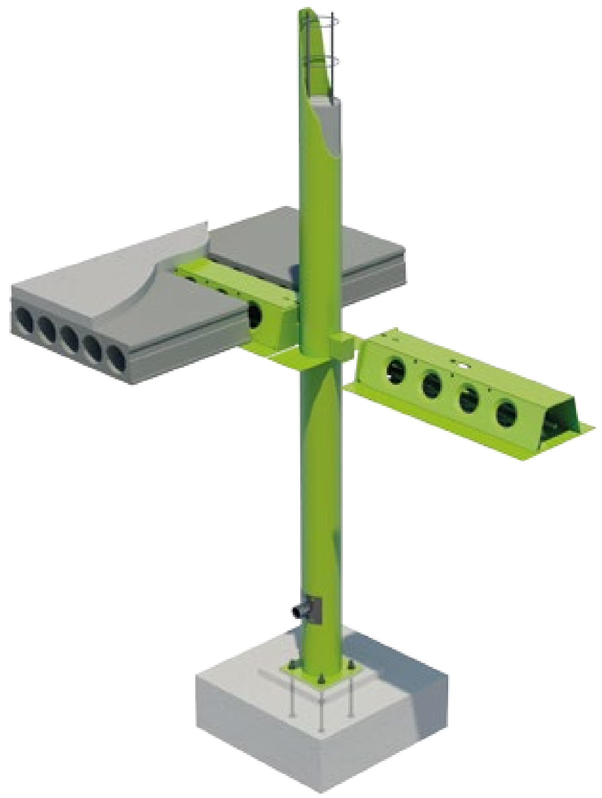


FIGURE 1 TYPICAL SECTION OF A DELTABEAM® FRAME

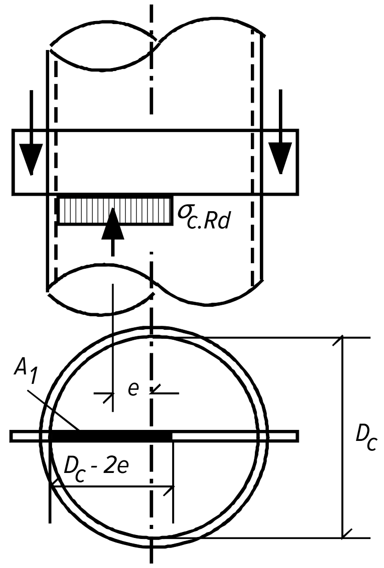



FIGURE 2 PRINCIPLES OF A GUSSET PLATE ARRANGEMENT AS GIVEN IN EUROCODE [1]"

Shear connectors are required in the region of load introduction if the shear strength is exceeded at the steel concrete interface. The design shear resistance value is given as 0.40 MPa for rectangular and 0.55 MPa for circular hollow sections. The resistance values require that the steel surface in contact with the concrete is free from oil, loose scale and other impurities, which might have a negative effect on the shear action. The shear introduction length is defined so that it should not exceed 2d of L/3, where d is the minimum transverse dimension of the hollow section, and L is the column length.

In the case the shear resistance is exceeded, Eurocode suggests two types of solutions for arranging a mechanical shear connection. The simplest way is to add headed studs in the load introduction region where the studs may be designed as with composite beams. The second method is a so called gusset plate piercing the whole composite section (Figure 2). This solution is discussed as a plate corbel further in this paper.

With the plate corbel, the vertical reaction is distributed between the column profile and the concrete section underneath the plate. Due to partial loading, the local strength of concrete can be multiple times higher than the regular compressive strength of concrete. The strength of the connection between the plate and the column profile is not defined in the Eurocode, but the design can be adopted elsewhere from the literature. E.g. an analogy can be drawn to a gusset plate connection (Figure 3) defined in CIDECT Design guide 1 [2].

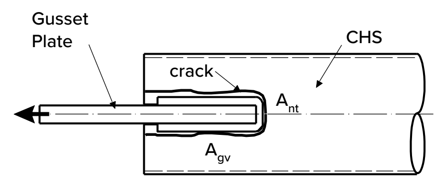



FIGURE 3 GUSSET PLATE CONNECTION DEFINED IN CIDECT DESIGN GUIDE [2]

## TEST SERIES

### INTRODUCTION

The scope of the test series was to broaden the knowledge regarding the load transfer behavior of a composite column in the vicinity of the load introduction. The main principles are available from the standards and from the literature, but design of an advanced joint requires assumptions which are critical to overall behavior. These tests were to examine those assumptions.

Where the preliminary tests concentrated on the principals of the shear transfer, the later tests with the corbels were to provide information about the behavior of a specific joint type. The specimens and the loading setup were planned so that they would represent a composite section taken out from a typical continuous multi story column.

The test series consisted of three different specimen types. The preliminary test series included only the type A specimen with direct load introduction (Figure 4a). The later test series included type A specimens as a reference, type B with surface corbel setup below (Figure 4b), and type C with plate corbel setup (Figure 4c) .

### PRELIMINARY TESTS

Before the actual corbel tests, a relatively extensive study was arranged including specimens with direct loading (Figure 4a) to study the characteristic of the plain shear stress between the steel tube and the internal concrete. The aim of the study was to gather background knowledge and to define the most critical variables regarding the shear strength for planning the test series with corbels.

The preliminary study consisted of 13 groups with 4 identical specimens in each group, extending the total amount of specimens to 52. The steel tubes used for forming the specimens were selected so that they represent the variety of delivery conditions of several tube manufacturers. All steel tubes were circular, longitudinally welded and nominally graded as S355 structural steel. Prior to concreting the specimens, the dimensions and the material properties of the steel tubes were measured. Also, the condition of the internal surface was defined by the surface roughness tester and visually. Simultaneously with concreting the test specimens, a group of concrete specimens were cast to define the strength, the elastic modulus, and the shrinkage of the concrete. After concreting, all specimens were hermetically sealed to be opened at the moment of testing.

**The following characteristics were varied between the series:**

- tube diameter (139.6...406.4 mm) and wall thickness (4...10 mm);
- shear introduction length from 2 to 3 times the tube diameter;
- concrete grade (C30/37...C50/60);
- concrete age (28 and 365 d);
- internal surface of the steel tube (dry, oily, rusty).

The test loading was arranged so that the specimen was supported through the concrete section and the load was applied equally to the steel section. The loading was executed deformation controlled so that the slip reached 30 mm. The discussed slip was measured from the unsupported concrete surface i.e. the end of the specimen where the load was applied (Figure 4).

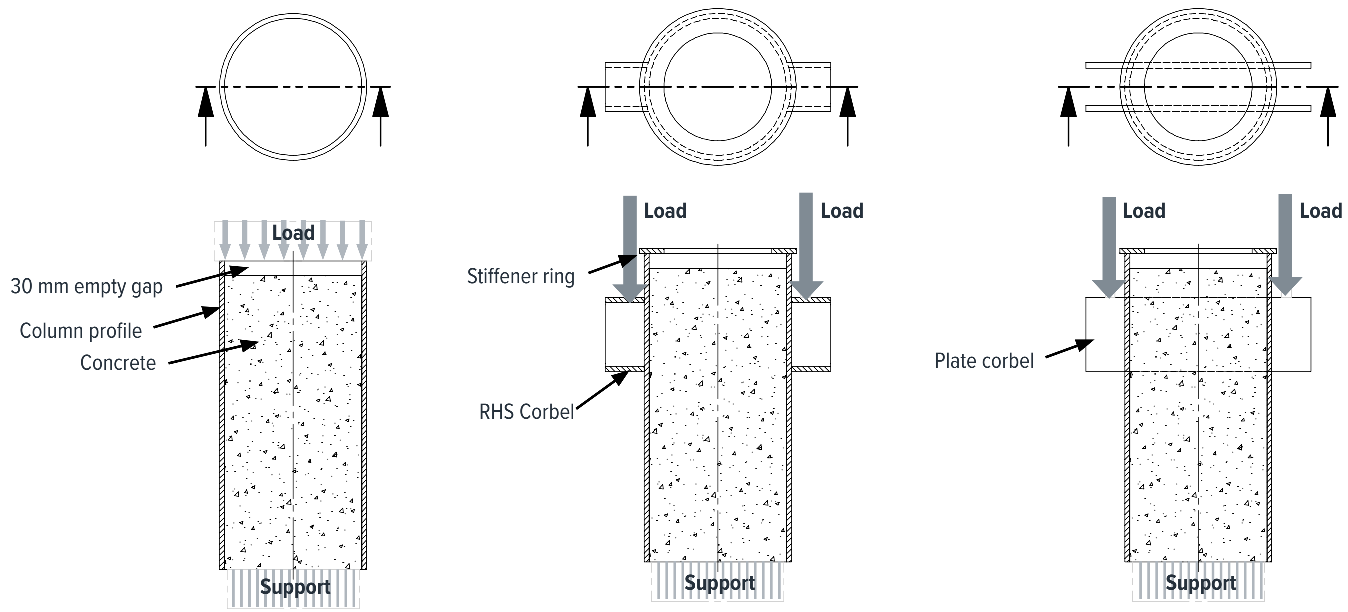



FIGURE 4 SPECIMEN TYPES



### SUMMARY OF THE RESULTS

The size of the steel tube did not have an effect to the achieved shear stress within the tested tube range. Neither the material properties of concrete of steel did not show any effect to the shear stress levels. The shrinkage of the hermetically stored concrete specimens remained low (0.0076...0.0172%) and the ageing of the concrete did not have an effect to the achieved shear stresses or the effect of small shrinkage might be compensated by the also small increase in the concrete strength. The shear introduction length did not have a significant effect to the shear stresses and the difference can be assumed to be caused by the distributions of the longitudinal strains along the steel tubes.

Even though there were quite a lot of variation in the conditions of the internal surfaces especially when inspected visually the roughness did not show any significant effect to the shear stresses. Some series were formed so that the rolling oil from the tube manufacturing process was left on the internal surface and the shear stresses remained notably low. The relative difference of the stress-slip behavior of oiled and optimal surface is illustrated in the Figure 5.

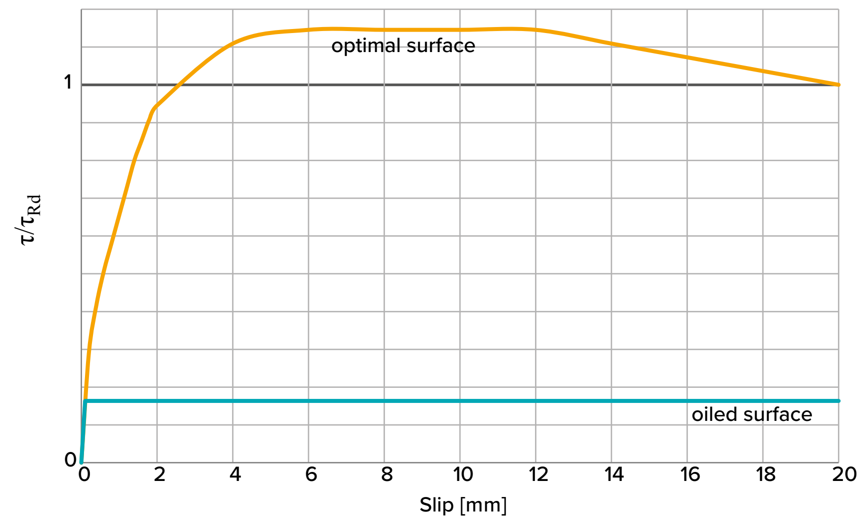



FIGURE 5 CHARACTERIZED SHEAR STRESS DEVELOPMENT AT THE INTERFACE BETWEEN THE STEEL TUBE AND CONCRETE CORE

### CORBEL TESTS

**The test with corbels were planned after the preliminary tests. The series consisted of 3 groups:**

1. Reference group (3 specimens) with the same direct loading arrangement as in the preliminary study (Figure 4a).
2. Surface corbel group (4 specimens) – the corbels were formed by welding RHS profiles on the surface of the column steel tube (Figure 4b). The group differed from the reference group only by the load introduction as the load was now applied trough the corbels.
3. Plate corbel group (4 specimens) – the corbels were formed by plates placed throughout the column steel tube and the concrete section (Figure 4c). The external corbel section had similar dimensional properties with the corbels tested within the surface corbel group. Now the difference to the surface corbel group were the corbel plates embedded to the concrete section providing a mechanical connection towards the shear load.

The specimens within the three groups had the circular steel tubes with diameter of 323.9 mm and thickness of 6 mm. The steel tubes were cut from the same blank and the length was defined so that the length of the steel concrete interface could be set to 2 times the tube diameter. Before concreting the specimens, the internal surface of the steel tube was examined to be similar to the “oiled surface”, as discussed in the chapter related to preliminary tests.

All the specimens were cast from the same concrete patch which was defined and tested to be grade C30/37. The grade of all steel parts was nominally S355. After concreting, the specimens were hermetically sealed to be opened at the moment of testing after 28 days.

The loading was arranged identically with the preliminary tests with the exception with corbel specimens where the load was applied on the corbels. The eccentricity of the resultant of the load from the surface of the column was 30 mm and the length of the loaded area in the direction of the longitudinal axis of the corbel was 20 mm. This was to simulate the typical dimensions of a beam-to-column connection where the thickness of the beam end plate is 20 mm and the gap between the beam end plate and the surface of the column is also 20 mm.

FIGURE 6 SPECIMEN TYPE C UNDER TEST LOADING

**SUMMARY OF THE RESULTS**

The reference test with direct loading followed the outcome of the preliminary tests. The initial stiffness of the specimens with surface corbel was similar to what was experienced in direct loading (Figure 7). When the slip exceeded approx. 0.4 mm where shear stress development stopped with directly loaded specimens, the stress development continued until the end of the test (30 mm). The shear stress development with the surface corbel type can be assumed to be resulting from the corbels rotating due to the eccentric loading and causing a compression zone on the bottom end of the corbel. The slip reading includes also the deformations of the corbel but based on the low final deformations in the vertical direction, this can be ignored and slip readings of directly loaded specimens and specimens with surface corbel compared.

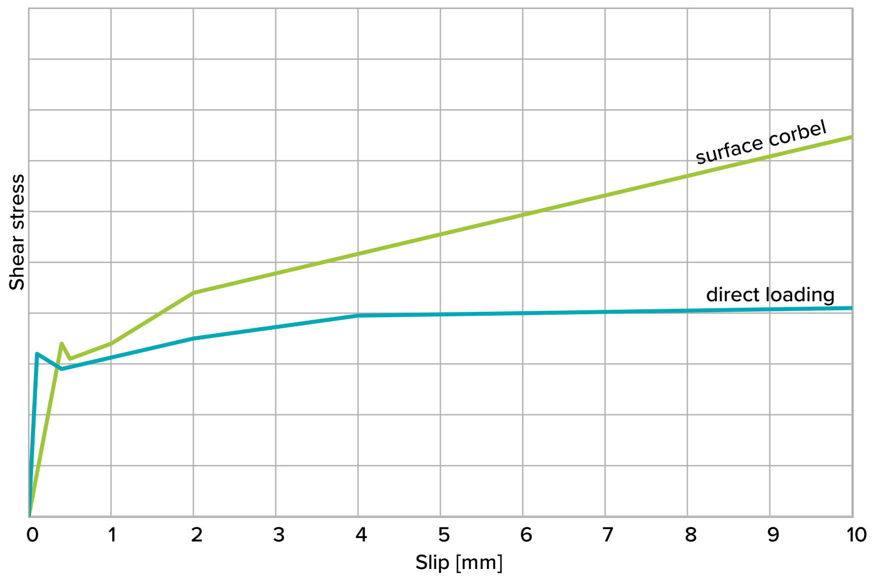
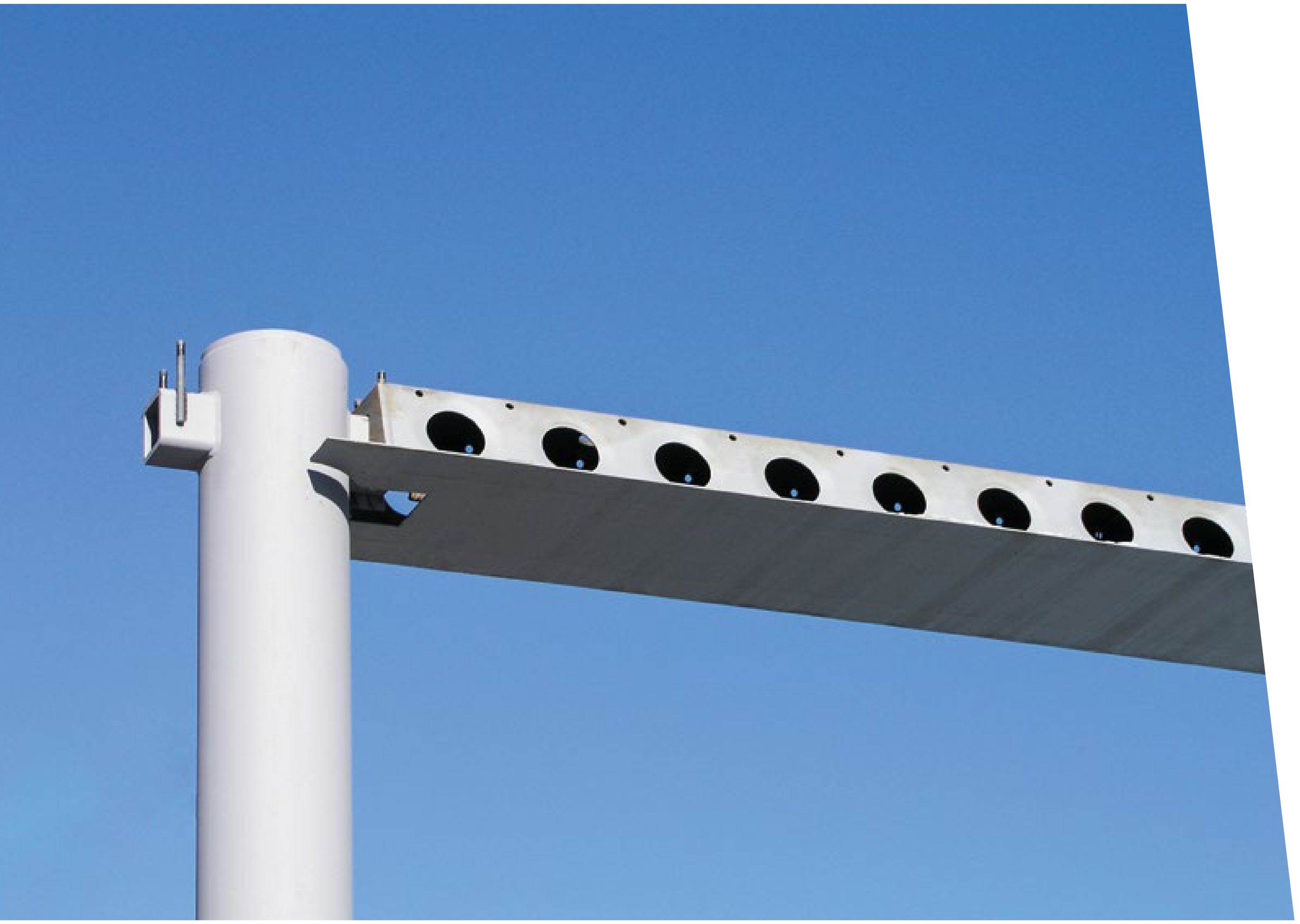



FIGURE 7 CHARACTERIZED STRESS SLIP CURVE OF THE SPECIMENS WITH DIRECT LOADING AND THE SURFACE CORBEL TYPE



With the plate corbel specimen type, the deformations were concentrated around the corbels, therefore the slip readings are not comparable to the other specimen types. The outer surface of the column steel tube was equipped with linear strain gauges and the most informative readings were taken from the gauges placed below the corbel measuring the vertical strain. The Figure 8 compares the measured strain to the total vertical deformation. Here the total deformation includes also the deflection of the corbels, whose significance increases when approaching the end of the loading.

The loading of the plate corbel specimens was stopped with lower deformations than when compared to two other specimen types. This was due to the load transfer from the corbels to the whole column cross section was stiffer than expected and load build up was mainly limited by the steel corbel itself.

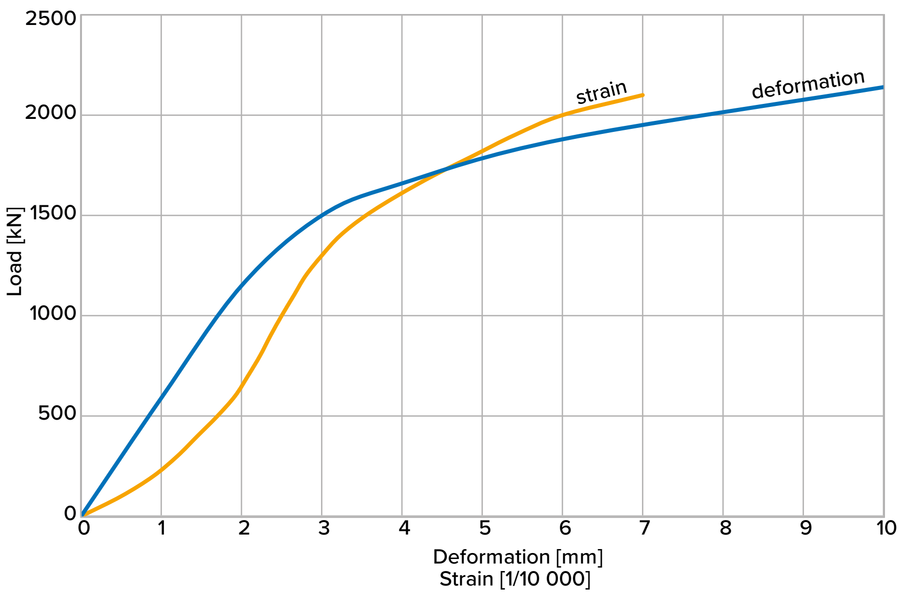



FIGURE 8 COMPARISON OF THE TOTAL DEFORMATION TO THE VERTICAL STRAINS MEASURED BELOW THE CORBEL

**DISCUSSION OF THE STUDY**

When an external action is to be transferred to a composite section, often the challenge is to activate the whole composite section. In the optimal situation, the introduced load can be distributed according to axial stiffnesses of the cross section members. With the plate corbel type of arrangement, where the piercing plate works as a stiff shear transferring device, this optimal state can be reached. The conditions in the concrete in the vicinity of the plate allow for the confining action and thereby high local stress of concrete.

The shear transfer based on adhesion and friction showed relatively large variance in the obtained shear stress levels, even though the shear interface met the cleanliness requirements. It may be that in the real structures the length of the active interface is longer than what is defined as the maximum length in the Eurocode.

The latest test series was in agreement with the assumptions regarding the plate corbel. The results, more precisely the strain readings, showed that the portion which is transferred directly to the concrete section is greater than assumed. The distribution of the load across the cross section is strictly dependent on the strains and here the stress strain relation of the concrete under the plate behaved stiffer than expected. The study highlights that to ensure the transfer of vertical shear forces in a safe and ductile manner, a level of mechanical shear connection is required at the interface between the column profile and the concrete. The transfer based on adhesion and friction is better suited for low forces from secondary structures.

**REFERENCES**

[1] EN1994 1 1:2004, Eurocode 4: Design of composite steel and concrete structures, Part 1: General rules and rules for buildings, CEN, 2004
[2] Design guide 1, For circular hollow section (CHS) joints under predominantly static loading, CIDECT, TÜV Verlag Rheinland, 1st edition, 1991

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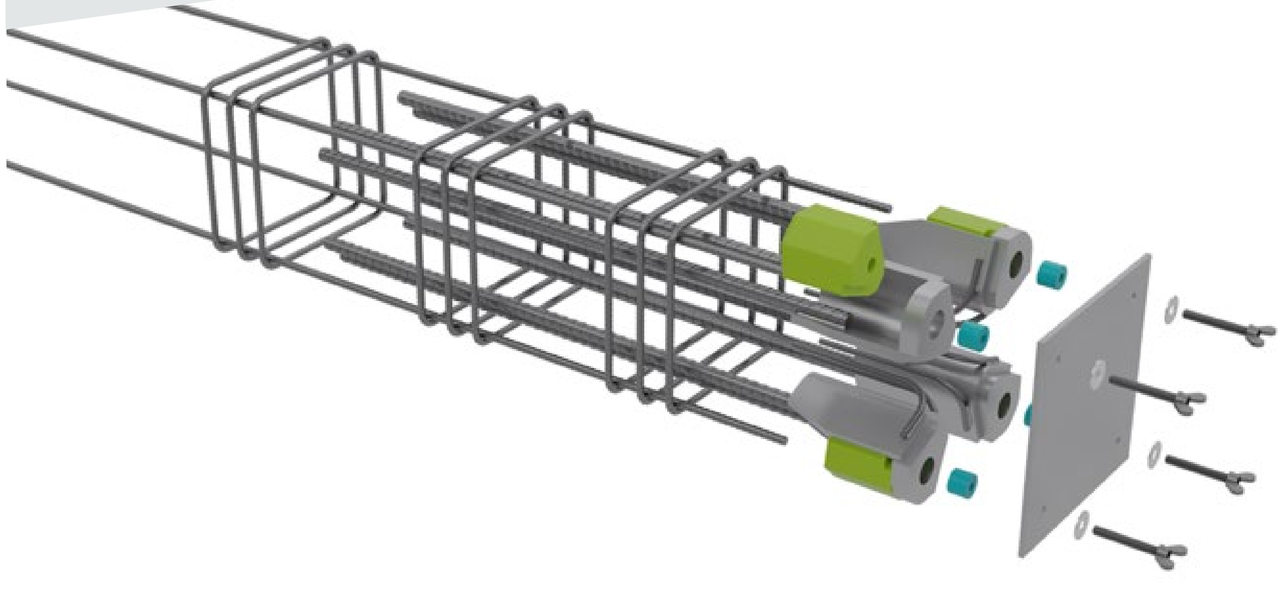

# NEW GENERATION OF COLUMN SHOE CONNECTIONS

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## INTRODUCTION

BOLDA® Column Shoes are fastening components used to create cost-effective stiff connections between precast concrete columns and foundations or between precast columns and other columns. Precast concrete columns show many competitive advantages, including speed of construction, smallest tolerances, high fire resistance, and high quality. Connections between precast columns are quick and easy to install, while also being economical. Peikko Group aims to make the design process quicker and easier. ETA's based on common understanding within the test procedures simplify designers' work, because the same design rules and methods, essentially a common design language, are valid and can be used all over Europe, and they are also widely accepted outside of Europe.

The development of the column shoe connections started at Peikko already in the early '80s. Since then, more than 50 large scale tests have been carried out in accordance with the respective up-to-date guidelines.

Below, the development and improvement of Peikko column shoe connections and the evaluation of various experimental and theoretical investigations are presented in detail.

## CE MARKING

In 2013, the Construction Products Regulation (CPR) replaced the Construction Products Directive (CPD). The CPR is directly applicable in all member states, whereas the CPD had to be implemented through national legislation.

The European Technical Approvals (ETApp) issued until June 2013 remain valid until the end of their validity period and in some cases also contain supplementary regulations for design. These "old" ETApp will be replaced by 2018 with a new type ETA, the European Technical Assessment (ETAss). According to the Construction Products Regulation, the new European Technical Assessments – in contrast to the European Technical Approvals – no longer have a validity period. It should be noted that the European Technical Assessments ETAs may no longer contain design provisions.

The new ETAss are issued based on European Assessment Documents (EAD). Existing Guidelines for European Technical Approval (ETAG) can be used as EAD on a transitional basis. The documents of a "Common Understanding of Assessment Procedure" (CUAP) must be transferred to an EAD if a European Technical Assessment is to be issued in future based on these documents.

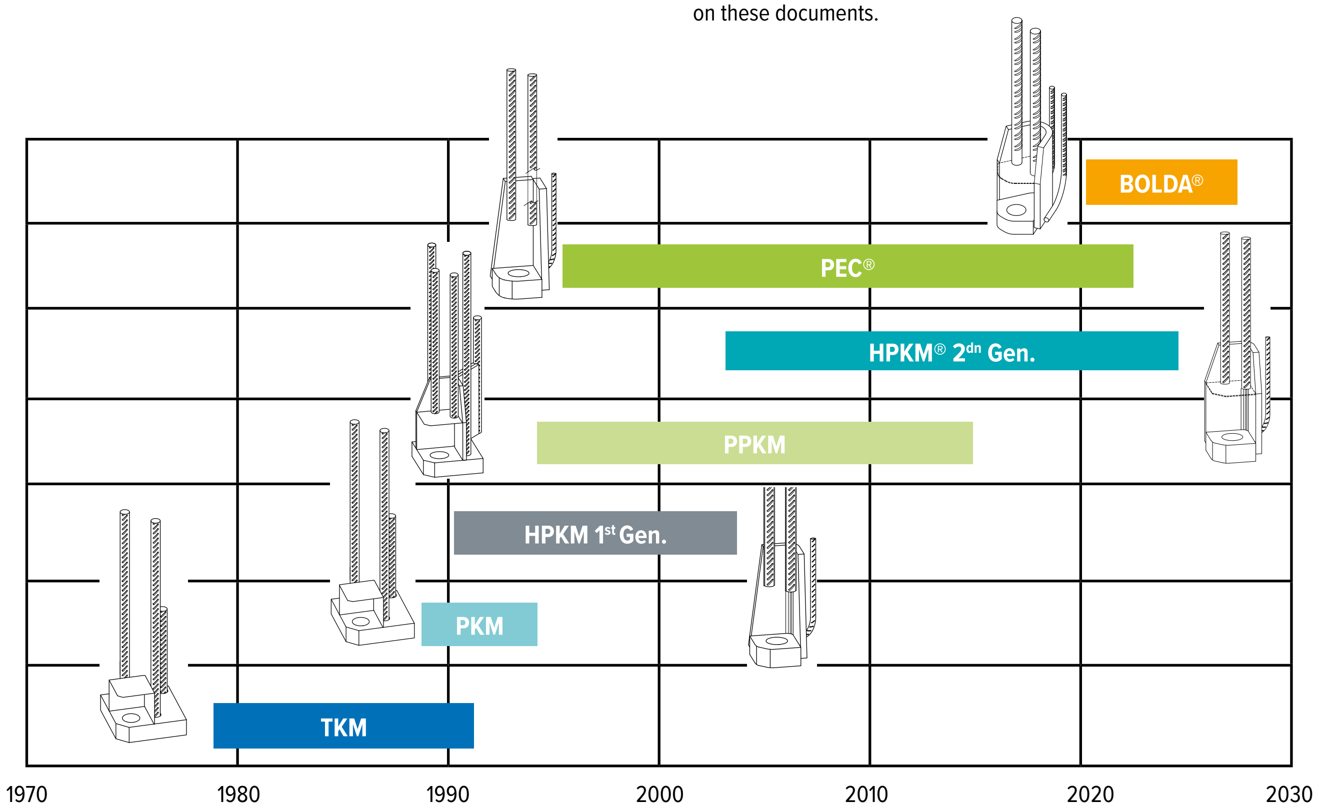



FIGURE 1: CHRONOLOGICAL DEVELOPMENT OF PEIKKO COLUMN SHOE SYSTEMS

A European Technical Assessment is issued by a Technical Assessment Body (TAB). The European TABs are organized in the European Organization for Technical Assessment (EOTA).

Based on an ETA, a certificate of constancy of performance and a declaration of performance (DoP) of the manufacturer, a CE marking may be affixed to the products. In the current phase of change, national approvals, European Technical Approvals (ETA "old"), and European Technical Assessments (ETA "new") are available for various product groups. CE marking is therefore a declaration that the product meets certain safety requirements such as mechanical and/or fire resistances. The application for a European Technical Assessment of EOTA (ETA) and the associated CE marking is voluntary. The ETA contains all required characteristic values, which have been obtained and verified according to the recognized rules of technology. It is the unique opportunity to describe the performance characteristics of column shoe systems.

Peikko's approach is much more comprehensive – not only the safety-relevant properties of a product are in focus, but also the corresponding technical rules and dimensioning regulations are constantly improved and further developed with the aim of providing faster and more efficient system solutions for the user. This supports further development of reinforced concrete construction in the long run.

## BOLDA® COLUMN SHOES

### GEOMETRY

BOLDA® column shoe connections are used to create cost-effective moment resisting stiff connections between precast concrete columns and foundations, or between precast concrete columns.

The system consists of column shoes and corresponding anchor bolts. Column shoes are cast into precast a concrete column, whereas anchor bolts are cast into foundation or another column. On construction site, the columns are erected on the anchor bolts, adjusted on the correct level and vertical position, and fixed to the bolts. Finally, the joint between column and base structure is grouted (Figure 2).

The BOLDA® column shoe (see Figure 3) consists of a horizontal base plate, vertically arranged side plate, vertical main anchorage bars and bent rear bars. Additional non-structural steel sheets, which serve as moulds when concreting the column, may be present. The components of the column shoe are connected to each other by welding.

The main dimensions of the different sizes of BOLDA® column shoes are given in Figure 4.

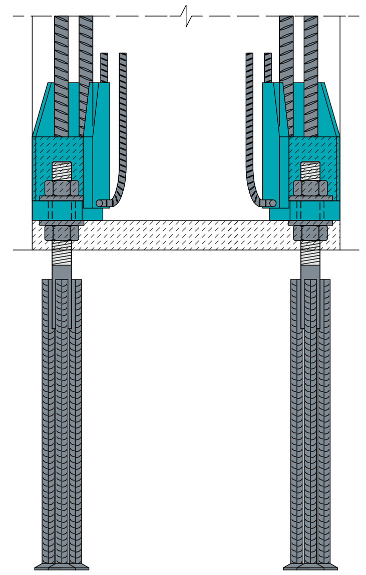


FIGURE 2: EXAMPLE FOR AN APPLICATION WITH BOLDA® COLUMN SHOE

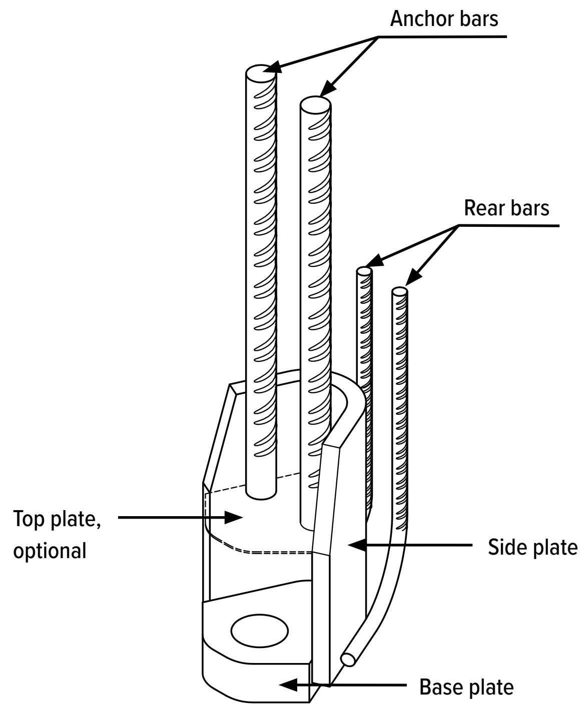
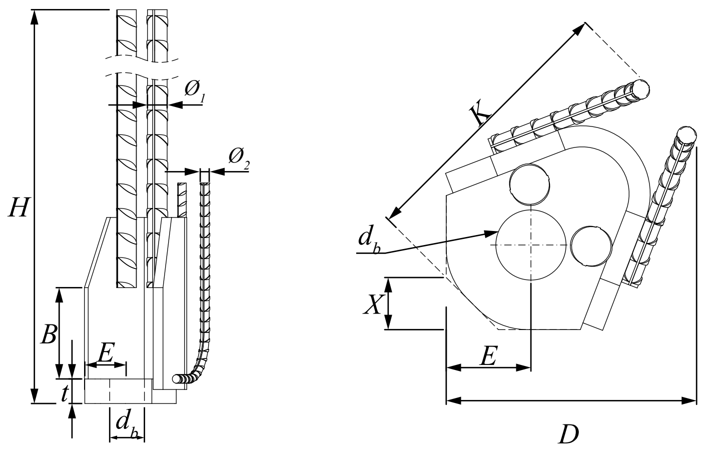
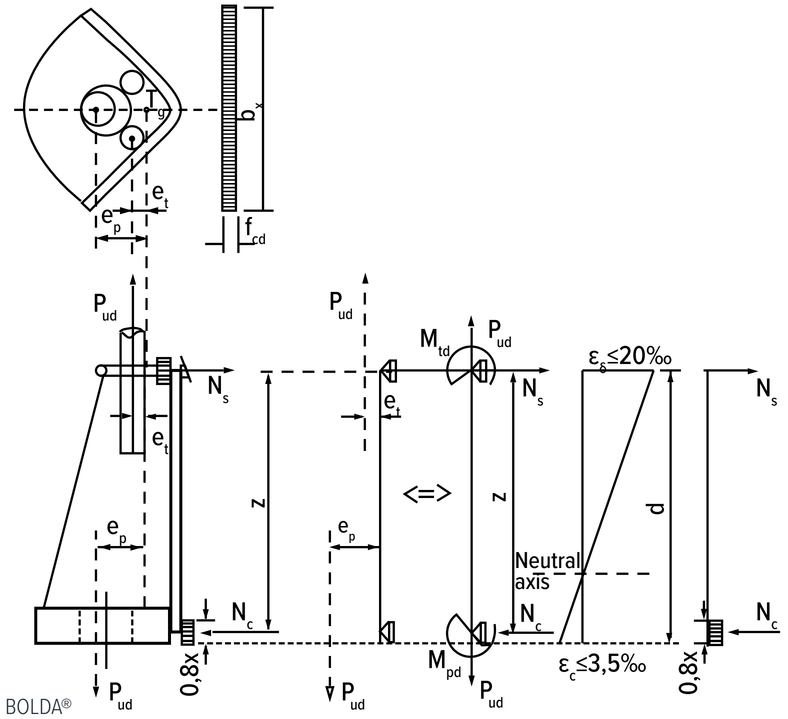



FIGURE 3: BOLDA® COLUMN SHOE

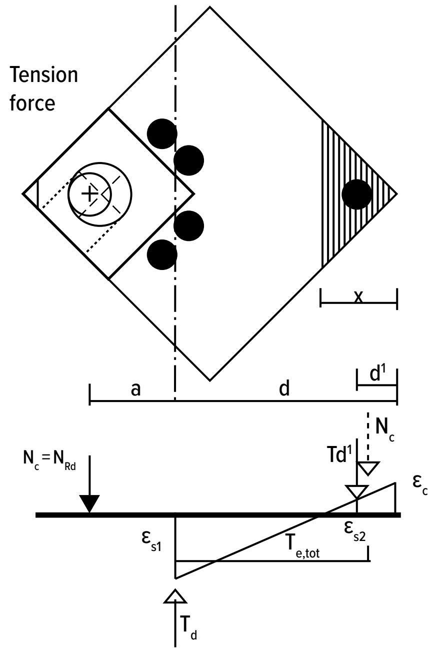



| | BOLDA® 30 | BOLDA® 36 | BOLDA® 39 | BOLDA® 45 | BOLDA® 52 |
|---|---|---|---|---|---|
| *H* | 1058 | 1365 | 1600 | 1852 | 2190 |
| *t* | 30 | 35 | 40 | 50 | 55 |
| *B* | 100 | 130 | 130 | 140 | 170 |
| *E* | 50 | 60 | 60 | 60 | 70 |
| $d_b$ | 40 | 50 | 55 | 60 | 70 |
| $Ø_1$ | 25 | 28 | 28 | 32 | 40 |
| $Ø_2$ | 10 | 12 | 14 | 16 | 16 |
| *X* | 30 | 37 | 37 | 37 | 42 |
| *D* | 153 | 178 | 195 | 217 | 245 |
| *K* | 173 | 200 | 220 | 250 | 269 |
| Weight | 13.7 | 22.6 | 29.4 | 42.5 | 74.9 |

FIGURE 4: DIMENSIONS [MM] AND WEIGHTS [KG] OF BOLDA® COLUMN SHOES




A) BOLDA®



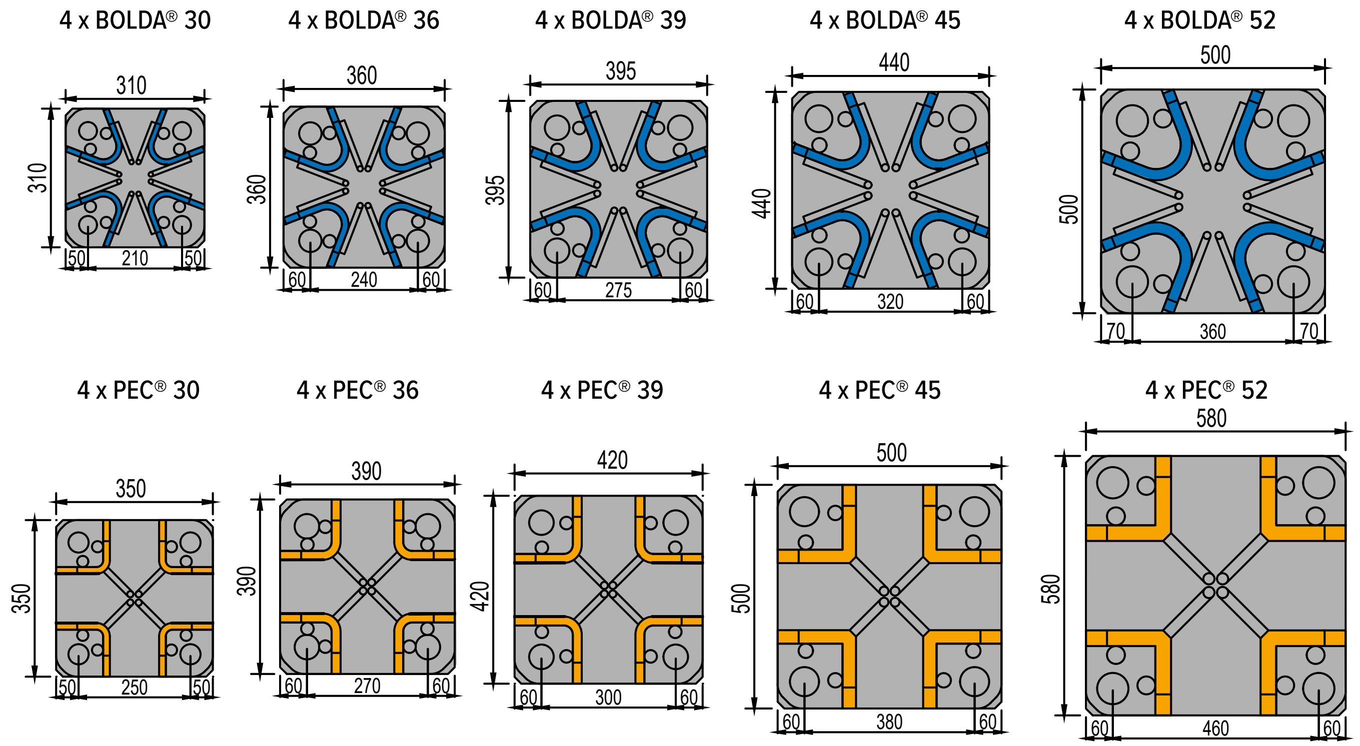

B) TKM/PKM

FIGURE 5: LOAD TRANSFER MECHANISM OF DIFFERENT COLUMN SHOE SYSTEMS FOR TENSION FORCES WITHIN THE ANCHOR BOLTS

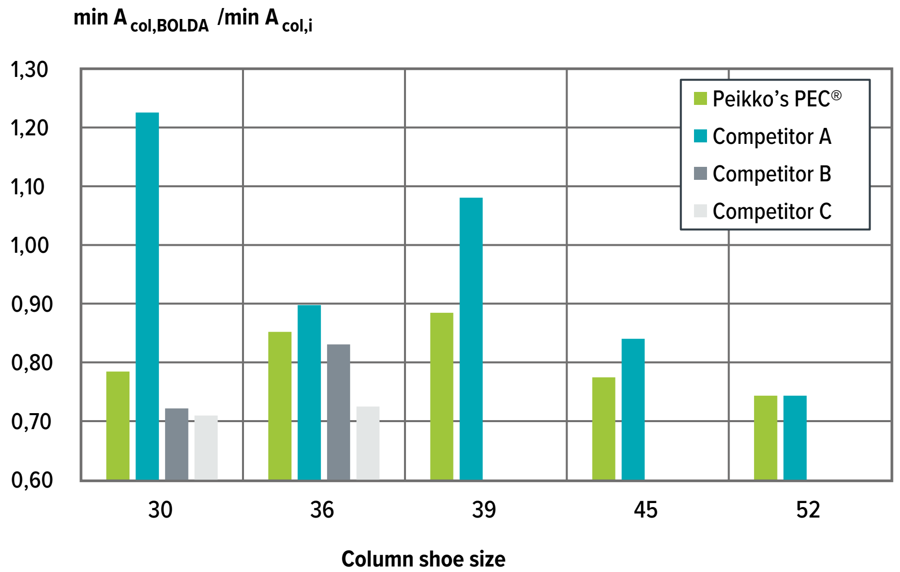
### LOAD TRANSFER MECHANISM

Column-to-column or column-to-foundation connections are usually loaded by axial normal forces and horizontal shear forces in combination with bending moments. The bending moments may be separated in pairs of tension and compression forces. The shear forces are transferred from one concrete element to the other via the cross section of the bolt. Additional friction forces may be generated if compressive forces are present. The tension forces in the baseplate are transferred by the anchor bolts to the base structure. Due to axial shift between the through-hole in the baseplate (= axis of the anchor bolt) and the axis of the anchor bars of the column shoe, an eccentricity appears. This eccentricity is compensated for by a pair of horizontal pair of forces (see Figure 5 a). In case of tension loads in the anchor, the moment due to eccentricity is taken over by a tension force in horizontally arrange stirrups and the compression force acting on the side plate. By contrast, the compression forces in the anchor bolts lead to the compression forces on the upper part of the side plate, and the tension forces in the horizontal part of the rear bars.

With the older versions of column shoes TKM and PKM, the eccentricity of the force within the anchor bolt was compensated with a vertical pair of forces consisting of the connecting reinforcement of the column and the vertical hanger reinforcement welded to the column shoe (see Figure 5 b).




A) GEOMETRY OF COLUMN CROSS SECTIONS FOR BOLDA® AND PEC® COLUMN SHOES




B) COMPARISON

FIGURE 6: MINIMUM REQUIRED COLUMN CROSS SECTIONS OF BOLDA® COLUMN SHOES COMPARED TO PEC® COLUMN SHOES AND TO VARIOUS COMPETITORS

### CONSTRUCTIONAL IMPROVEMENTS

Further changes to improve the overall stiffness of the column shoes have been made. Already during the development process of HPKM® column shoes we realized that building a straight form of the side plate up to the starting point of the anchor bars increases the stiffness of the connection. With BOLDA®, the outer edges of the base plate as well as the side plates are only inclined at 48° to each other instead of the 90° for previous systems TKM or PKM, which in turn leads to increased stiffness. This reduced angle in combination with the different positioning of the rear bars results in a significant reduced space requirement for each column shoe, which consequently leads to 12% to 26% smaller column cross sections compared to predecessor type (compare Figure 6).

During the development process, efforts were also made to further improve and streamline the production process. This was achieved, for example, by optimizing the number of welding seams, which subsequently improves indirectly the overall safety due to minimization of error-proneness.

Due to the above-mentioned improvements, the overall form of the BOLDA® column shoes is more compact and stiffer compared to older versions. BOLDA® column shoe enables 20% slimmer cross-sections compared to PEC®.

In combination with the optimization of the production process, a significant reduction in the overall $CO_2$ footprint was achieved.

## INVESTIGATIONS
### EXPERIMENTAL

**General**

There is no one-to-one correspondence between the mechanical resistance of a column shoe as delivered and the mechanical resistance of a column shoe connection. A connection is subjected to various action effects like axial force, shear force, and bending moment in different combinations, and the stiffness of the connection also has an impact on the behavior and the design of the column. It is impossible to determine the mechanical resistance or stiffness of a column shoe connection as a set of values determined according to different standards and guidelines. Therefore, these properties must be determined experimentally.

The EAD [1] summarizes the required tests and the related test setup, and gives guidance on the evaluation of the test results. The values determined in this way can then be used with the design method specified in TR 068 [2].

The following tests are mandatory according to EAD:

a) Bending Resistance Tests
b) Bending Stiffness Tests
c) Shear Resistance Tests
d) Fire Resistance investigations

**a) Bending Resistance (BR) Tests**

The target of the Bending Resistance (BR) tests is to show that the resistance of the BOLDA® column shoe connection is at least equal to the bending resistance of a monolithic cast-in-situ column.

**b) Bending Stiffness (BS) Tests**

In general, design of column-to-column or column-to-foundation connections with column shoes should follow the design principles given in EN 1992-1-1 for monolithic columns with continuous reinforcement. The stiffness of columns and the moment-deflection-behavior respectively is considered in EN 1992-1-1 by different buckling factors or buckling lengths. Therefore, within these tests it is verified whether for column shoe connections the same assumptions as for cast-in-situ columns apply. With column shoe connections (column A in Figure 7), different zones along the column length compared to cast-in-situ columns (column B in Figure 7) must be considered. Within **Zone 1,** columns with column shoe connections do not differ from cast-in-situ columns since the existing reinforcement is identical. In **Zone 2**, the flexural stiffness of column A with column shoes is much higher compared to column B. This is caused by the overlapping of the anchor rebars of the column shoe with the existing reinforcement of the column. In contrary, column B is designed with continuous reinforcement in **Zone 2** according to EN 1992-1-1 [4], even though in practice spliced reinforcement would be more common.

In **Zone 3**, the flexural stiffness of column A is lower compared to column B, mostly due to the reduced effective concrete section at the bottom of the column. Further reduction of the stiffness is caused by the eccentric tension forces in the column shoes (compare Figure 7). The schematic location of the measuring points along the length of the column is shown in Figure 8.

With cantilevered columns, the stiffness of the column shoe connection plays the most important role compared to other statical systems. The behavior of cantilevered columns is extremely sensitive to geometrical nonlinearity and therefore considerably influenced by the stiffness. Any negative effect caused by a flexible connection will be amplified within such system.

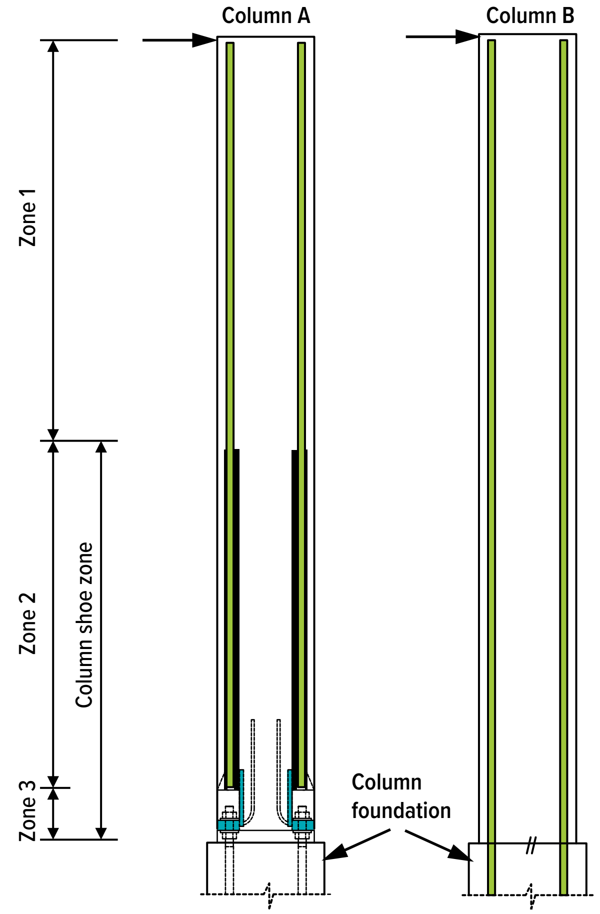



FIGURE 7: DIFFERENT STIFFNESS ZONES OF CANTILEVER COLUMNS

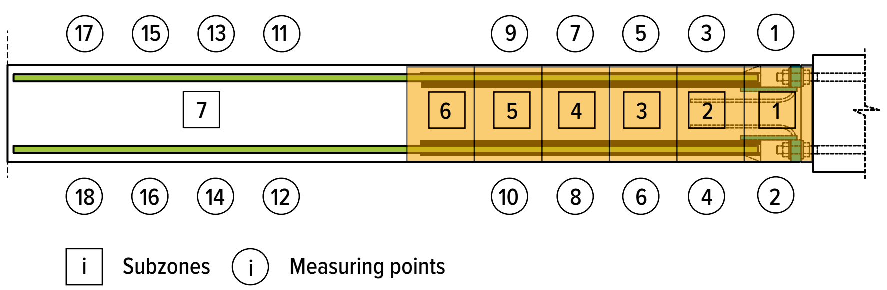



FIGURE 8: LOCATION AND NUMBERING OF THE SUBZONES AND MEASURING POINTS (TRANSDUCERS), SCHEMATIC

**c) Shear resistance tests**

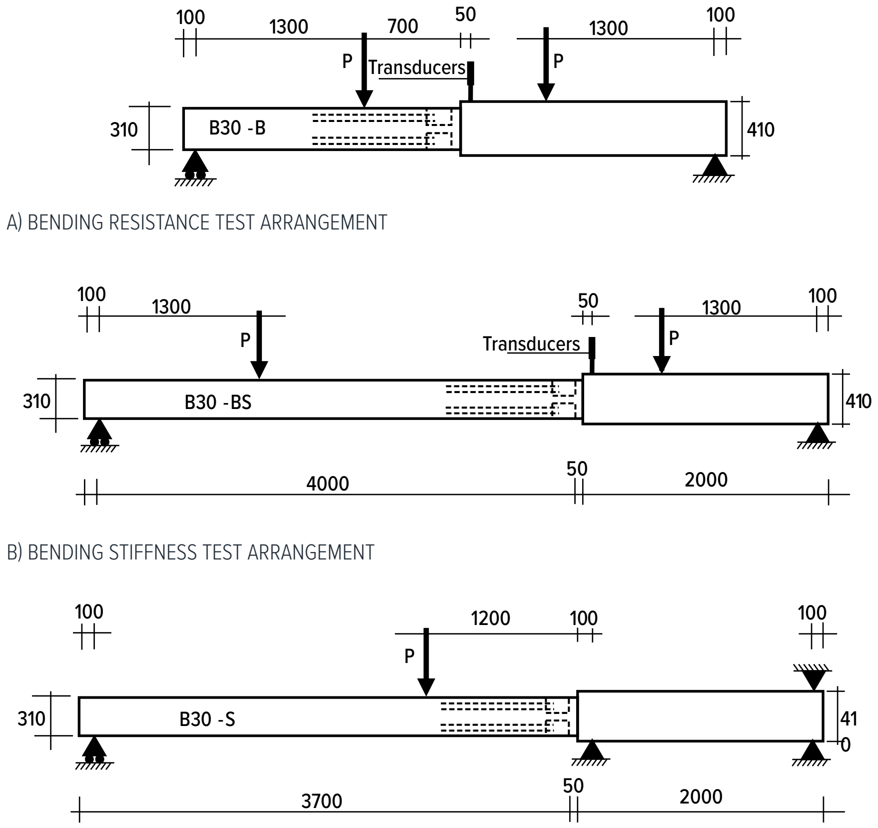
In the shear tests, it is assumed that the maximum shear forces are caused by a horizontal load at a certain distance from the foundation level (e.g. vehicle impact). The maximum shear resistances obtained in the tests are compared to the theoretical values of two acting columns shoes. The theoretical resistances are determined according to EN 1993-1-8 considering both the base plate and the bolt.

The different test setups for all three tests are shown in Figure 9.

## EVALUATION OF TEST RESULTS
### BENDING RESISTANCE

The observed bending resistance moment $M_{obs}$ and the related failure modes of the column shoe connections are summarized in Table 1. In the two tests, compression failure of the concrete and/or grout was observed. This means that the ultimate capacity of the column shoe was not reached, and the bending resistance moment is higher than the value given in Table 1. For this reason, these two tests will be disregarded in the further evaluation.

The theoretical bending resistance $M_t$ has been calculated acc. to EN 1992-1-1 considering the measured material properties for compressive strength of the concrete and the grout, yield strength of the rebars, as well as yield strength of the anchor bolts. According to EAD, the comparison of the test results with the theoretical values $m_k = (M_{obs}/(\eta_{d0} \cdot M_t))$ contains a bending resistance factor $\eta_{d0} \leq 1.0$ used for the design of the test specimen. This value was taken as $\eta_{d0} = 1.0$.




A) BENDING RESISTANCE TEST ARRANGEMENT

B) BENDING STIFFNESS TEST ARRANGEMENT

C) SHEAR TEST ARRANGEMENT

FIGURE 9: EXAMPLES OF TEST SETUP ACCORDING TO EAD [1]

The evaluation shown above clearly confirms that the load bearing behavior of the column with BOLDA® column shoe connection is equal compared to the behavior of a monolithic column.

| Test | $f_{gr}$ | b = d | $d_1$ | $f_{bolt,y}$ | $A_{sp}$ | $M_t$ | $\eta_{d,0}$ | $M_{obs}$ | $M_{obs}/(\eta_{d,0} \cdot M_t)$ | Failure mode |
|---|---|---|---|---|---|---|---|---|---|---|
| | MPa | mm | mm | MPa | mm² | kNm | - | kNm | - | |
| B30-BS.2 [1] | 53.2 | 310 | 50 | 803 | 561 | 209.8 | 1.00 | 215.7 | 1.03 | Bolt |
| B30-B [1] | 49.9 | 310 | 50 | 803 | 561 | 208.5 | 1.00 | 220.2 | 1.06 | Bolt |
| B30-BS.2 [2] | 48.2 | 380 | 50 | 918 | 561 | 311.3 | 1.00 | 330.2 | 1.07 | Bolt |
| B39-B [1] | 49.2 | 390 | 60 | 855 | 976 | 485.3 | 1.00 | 453.8 | - | concrete compression |
| B39-B [2] | 48.2 | 420 | 60 | 894 | 804 | 486.5 | 1.00 | 497.3 | 1.03 | Bolt/column shoe |
| B52-B [1] | 49.9 | 500 | 70 | 964 | 1758 | 1273.4 | 1.00 | 1084.9 | - | concrete compression |
| B52-B [2] | 40.9 | 580 | 70 | 890 | 1479 | 1214.6 | 1.00 | 1343.8 | 1.11 | Bolt/column shoe |
| B52-BS.2 [2] | 43.5 | 580 | 70 | 890 | 1479 | 1218.9 | 1.00 | 1322.3 | 1.09 | Bolt/column shoe |
| Mean value $m_m$ | | | | | | | | | 1.07 | |
| Standard deviation $s_m$ | | | | | | | | | 0.032 | |
| Characteristic value (unknown standard deviation) $m_k = m_m - k_n \cdot s$<br>Statistical factor acc. EN 1990: $k_n$ = 2,18 | | | | | | | | | 1,00 | |

TABLE 1: EVALUATION OF THE BENDING RESISTANCE TESTS, RESULTS FROM [9, 10]

### BENDING STIFFNESS

Two bending stiffness tests have been carried out using BOLDA® 30 and BOLDA® 52. The strains on the top and the bottom along the column axis have been determined by means of the measured differential displacement as given in Figure 9 b) and Figure 8. The bending stiffness of the column shoe connection is evaluated comparing the residual deflections determined in the tests with column shoe connections and monolithic columns see Figure 10). The subzones in Figure 10 are identical to the one shown in Figure 7 and Figure 8.

The bending moment in each subzone and the related stiffnesses in the middle of each subzone as well as the maximum bending moment at the bottom of the column are summarized in Table 2. The location of the subzones is as follows (compare Figure 7 and Figure 8):

- Subzone 1 is identical to Zone 3 = column shoe connection zone
- Subzones 2–5 are in the column shoe zone (Zone 2), whereas subzone 6 is located in the mixed zone at the end of the column shoe. The stiffness for subzone 6 is calculated using the mean value of measured deformations within subzone 5 and subzone 7.
- Subzone 7 is outside of the column shoe zone (= Zone 1). In this area, the reinforcement layouts of column A and B are identical and lead to equal stiffnesses. The stiffness for this subzone is calculated using the mean value of measured deformations of measuring points 11 to 18.

The maximum deflections at the top of the column, calculated from the relative subzone stiffnesses, are additionally shown in Table 2.

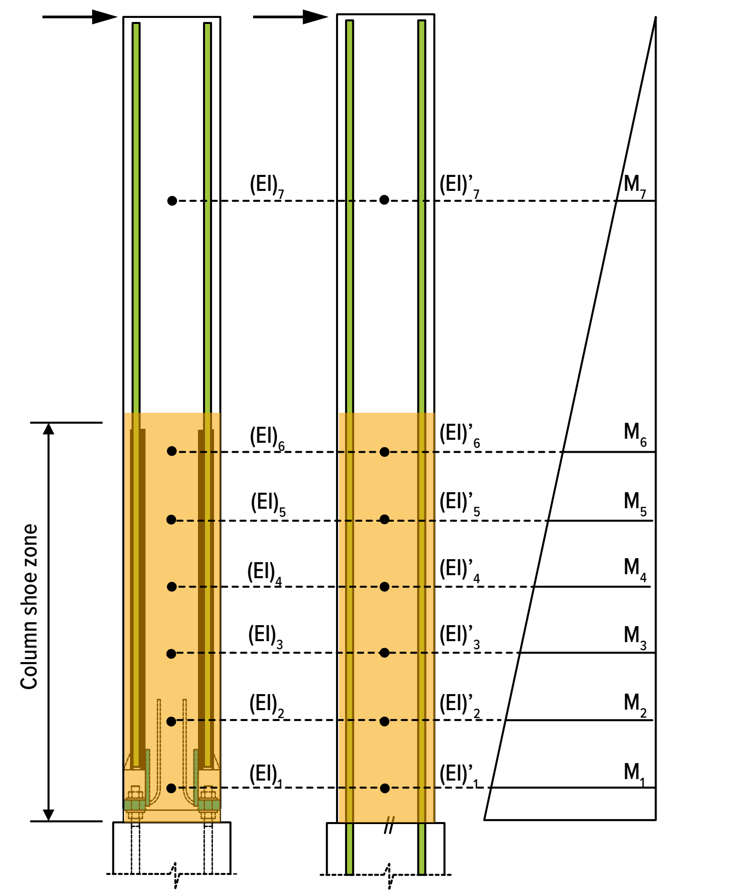



FIGURE 10: PROCEDURE FOR STIFFNESS COMPARISON

| | BOLDA® 30 | | | BOLDA® 52 | | |
|---|---|---|---|---|---|---|
| Subzone i | $M_i$ | Column A | Column B | $M_i$ | Column A | Column B |
| | | $(EI)_i$ | $(EI)'_i$ | | $(EI)_i$ | $(EI)'_i$ |
| | kNm | [MNm²] | [MNm²] | kNm | [MNm²] | [MNm²] |
| 7 | 60.5 | 4.69 | 4.69 | 384.7 | 101.36 | 101.36 |
| 6 | 123.1 | 9.65 | 6.00 | 784.9 | 131.51 | 114.56 |
| 5 | 129.1 | 13.14 | 5.90 | 823.9 | 147.17 | 113.32 |
| 4 | 136.8 | 13.05 | 5.88 | 871.3 | 162.73 | 112.78 |
| 3 | 144.6 | 12.22 | 5.71 | 918.6 | 169.71 | 111.62 |
| 2 | 152.3 | 9.22 | 5.15 | 966.0 | 190.58 | 109.74 |
| 1 | 160.1 | 3.24 | 5.03 | 1013.3 | 43.56 | 104.12 |
| $1.0 \cdot M_{t,0}$ | 163.9 | | | 1037.0 | | |
| Deflection | | $v_{shoe}$ | $v_{ref}$ | | $v_{shoe}$ | $v_{ref}$ |
| | | [mm] | [mm] | | [mm] | [mm] |
| | | 164.9 | 190.4 | | 261.6 | 249.3 |
| $v_{shoe}/v_{ref}$ | | 0.866 | | 1.049 | | |

TABLE 2: COMPARISON OF BENDING STIFFNESSES IN DIFFERENT SUBZONES AND CALCULATED DEFLECTIONS AT THE TOP OF THE COLUMNS, RESULTS FROM [9, 10]

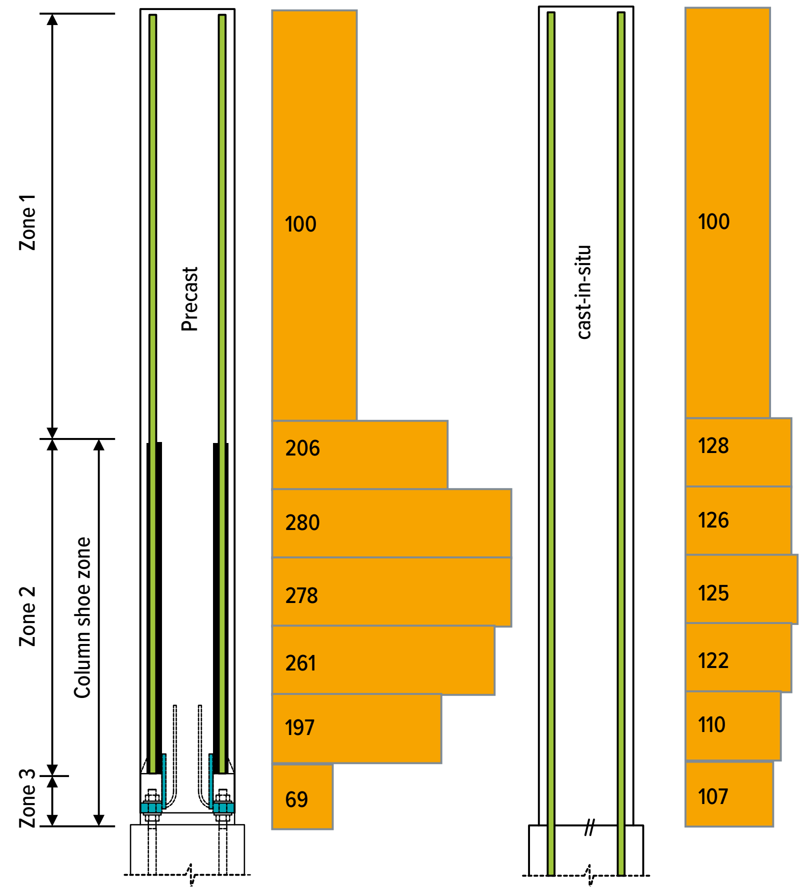



FIGURE 11: EVALUATION OF TEST RESULTS FOR COLUMNS A (BOLDA® 30) AND B – RELATIVE BENDING STIFFNESS OF SUBZONES IN %

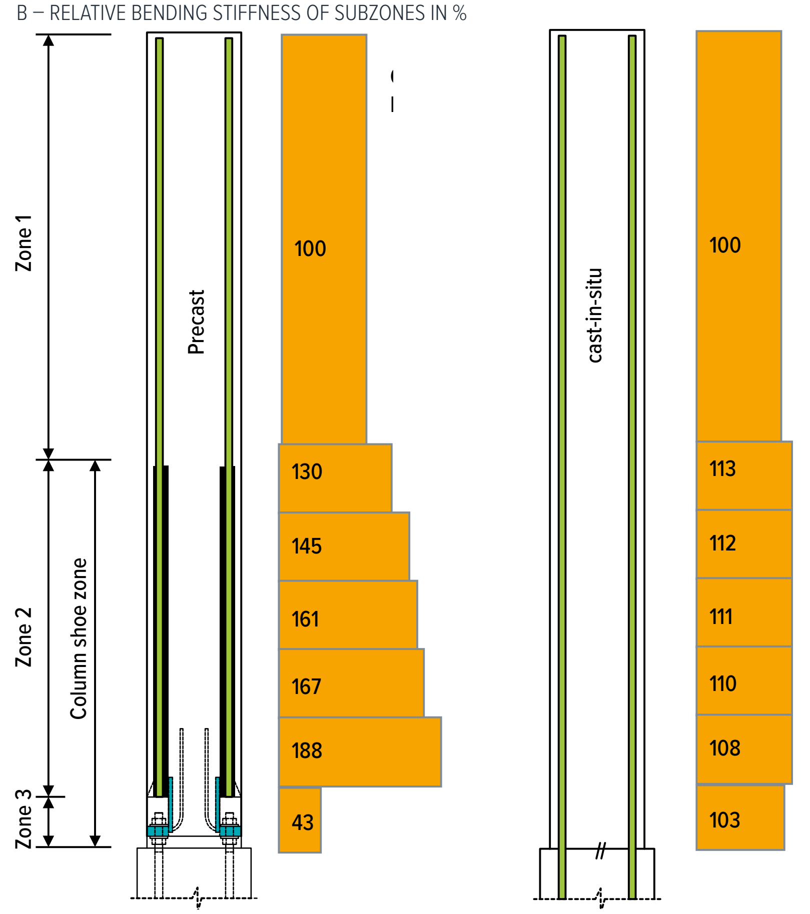



FIGURE 12: EVALUATION OF TEST RESULTS FOR COLUMNS A (BOLDA® 52) AND B – RELATIVE BENDING STIFFNESS OF SUBZONES IN %

Figure 11 and Figure 12 show the distribution of the bending stiffness along the column axis related to the bending stiffness of the undisturbed region (subzone 7). In zone 2, the stiffness of precast column A is for both sizes of BOLDA® column shoes significantly higher compared to the cast-in-situ columns. In Zone 3, the relative stiffness of precast column A is smaller than the value obtained for column B. Nevertheless, the higher stiffness of zone 2 will compensate for the lower stiffness in zone 3.

The calculated deflection at the top of the columns based on the measured deformations are $v_{shoe}$ = 165 mm (BOLDA® 30) and $v_{shoe}$ = 262 mm (BOLDA® 52). These values are ca. 13.4% lower (BOLDA® 30) and 4.9% higher (BOLDA® 52) than the reference values of the cast-in-situ columns. According to EAD [1], the ratio of is limited to $v_{shoe}/v_{ref} \leq 1.05$. Therefore, the requirements are fulfilled and a factor $k_L$ = 1.0 can be used in the design of the columns according to EN 1992-1-1 [4].

### SHEAR RESISTANCE

Two shear resistance tests using BOLDA® 30 and BOLDA® 52 have been carried out. The results are given in Table 4. The measured shear resistances $V_{u,test}$ have been converted to $V_{e,i}$ taking into account the ratio of nominal to actual steel strength ($f_u/f_{u,test}$). The values obtained are compared to the theoretical value $V_{t,i}$.

| Test | $V_{t,i}$ | $V_{u,test}$ | $f_u$ | $f_{u,test}$ | $f_u/f_{u,test}$ | $V_{e,i} = (f_u/f_{u,test}) \cdot V_u$ | $V_{e,i}/V_{t,i}$ |
|---|---|---|---|---|---|---|---|
| | kN | kN | MPa | Mpa | - | kN | - |
| B30-S [1] | 198.6 | 346 | 800 | 889 | 0.90 | 311.3 | 1.57 |
| B52-S [1] | 561.5 | 1176.7 | 800 | 1059 | 0.76 | 894.3 | 1.59 |

TABLE 3: COMPARISON OF THE RESULTS OF THE SHEAR TESTS WITH THE THEORETICAL VALUES

The comparison in Table 3 clearly shows that the requirement $V_{e,i}/V_{t,i} \geq 1.0$ is clearly fulfilled. Therefore, a value $k_s = 1.0$ can be used in the shear design according to EN 1992-1-1.

In the following, all characteristic values are listed.

| Column shoe | | | BOLDA® 30 | BOLDA® 36 | BOLDA® 39 | BOLDA® 45 | BOLDA® 52 |
|---|---|---|---|---|---|---|---|
| Steel failure | | | | | | | |
| Resistance | $N_{Rd,s}$ | [kN] | 299 | 436 | 521 | 697 | 938 |
| Bending resistance factor | $\eta_d$ | [-] | 1.0 | | | | |
| Bending stiffness factor | $k_L$ | [-] | 1.0 | | | | |
| Shear resistance factor | $k_s$ | [-] | 1.0 | | | | |

| Material | Properties | |
|---|---|---|
| Concrete | Compressive strength $f_{ck}$ | 30 MPa |
| | Tensile strength $f_{ctk}$ | 2.0 MPa |
| | Youngs modulus E | 32000 MPa |
| Mortar | Compressive strength $f_{ck}$ | 50 MPa |
| | Tensile strength $f_{ctk}$ | 2.9 MPa |
| | Youngs modulus E | 37000 MPa |
| PPM® bolt and nut | Yield strength $f_{yk}$ | 640 MPa |
| | Ultimate strength $f_{uk}$ | 800 MPa |
| | Youngs modulus E | 200000 MPa |
| BOLDA® column shoe plates | Yield strength $f_{yk}$ | 355 MPa |
| | Ultimate strength $f_{uk}$ | 490 Mpa |
| | Youngs modulus E | 200000 MPa |
| Reinforcement | Yield strength $f_{yk}$ | 500 MPa |
| | Ultimate strength $f_{uk}$ | 600 MPa |
| | Youngs modulus E | 200000 MPa |

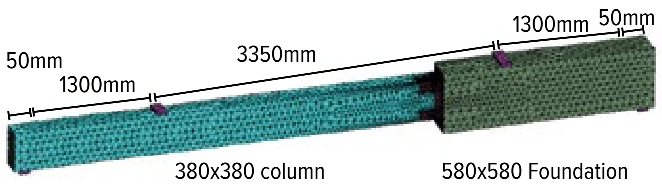
TABLE 4: MATERIAL PROPERTIES OF THE COMPONENTS WITHIN THE FE CALCULATIONS [18]

### ADDITIONAL INVESTIGATIONS OF THE DEFLECTION BEHAVIOR WITH FE ANALYSIS

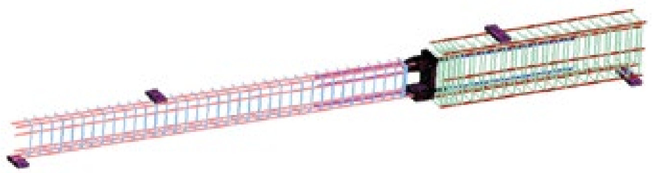
To further evaluate the load bearing behavior of column shoe connections in comparison to cast-in-situ columns, a small research project using finite element analysis of both systems has been conducted in collaboration with University of Stuttgart [18]. Two systems applying BOLDA® 30 and BOLDA® 52 column shoe connections have been investigated, as well as the associated cast-in-situ (monolithic) models. The test setup for the bending stiffness, tests acc. to Figure 9 b) including the measuring points according to the previous section have been adopted for both column shoe connections as well as monolithic cast-in-situ systems. Within the analysis, the following material properties for the different components have been used (Table 4).

The non-linear finite element program ATENA® can simulate the real structural behavior including concrete cracking, crushing and reinforcement yielding. The software has been extensively validated on experimental data and international round robin prediction analysis.

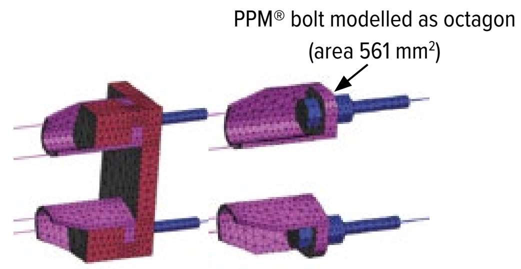
Within the FE-model, the concrete (foundation, column and mortar) and steel (shoe plates, bolts and nuts, loading/support plates) were modelled as solid elements, whereas the reinforcement (longitudinal bars and transverse stirrups, anchor bars) are modelled as 1D-beam elements with axial degree of freedom. The contact areas between reinforcement and concrete, as well as the contact areas between different solid elements, are described with a bond model. Figure 13 a) shows the complete system of solid elements and Figure 13 b) shows the discretization of the longitudinal and stirrup reinforcement, and Figure 13 c) shows the details of the FE-model of the column shoes.




A) SOLID ELEMENTS OF COLUMN, FOUNDATION AND LOADING/SUPPORT PLATES



B) 1D-BAR ELEMENTS OF THE REINFORCEMENT [18]




C) FE-MODEL FOR THE COLUMN SHOE [18]

FIGURE 13: FE-MODEL OF THE COMPLETE SYSTEM (PPM® BOLT MODELLER AS OCTAGON WITH AREA = 561 SQMM)

Figure 14 show the calculated load/moment-deflection curves of the column-foundation-system with BOLDA® 30 compared to the monolithic system. The deflections are given for the loading point in the column- and foundation-area, as well as for the position of the transducer close to the joint between column and foundation (compare Figure 9 b). In Figure 15, the crack development at different load steps are shown.

In general, the deflections increase linearly with increasing loading up to ca. 85% of the ultimate load. With further loading, the deflections increase over proportional with increasing load. This is mainly caused by progressive cracking, as well as exceeding the yield strength of the reinforcement. Failure load of the connected and the monolithic system differ only slightly by ca. 2%. Within the linear area, the deflections of the monolithic system are ca. 15% larger than the calculated values of the column shoe system (compare Figure 14). This difference is significantly increasing after passing the yield load.

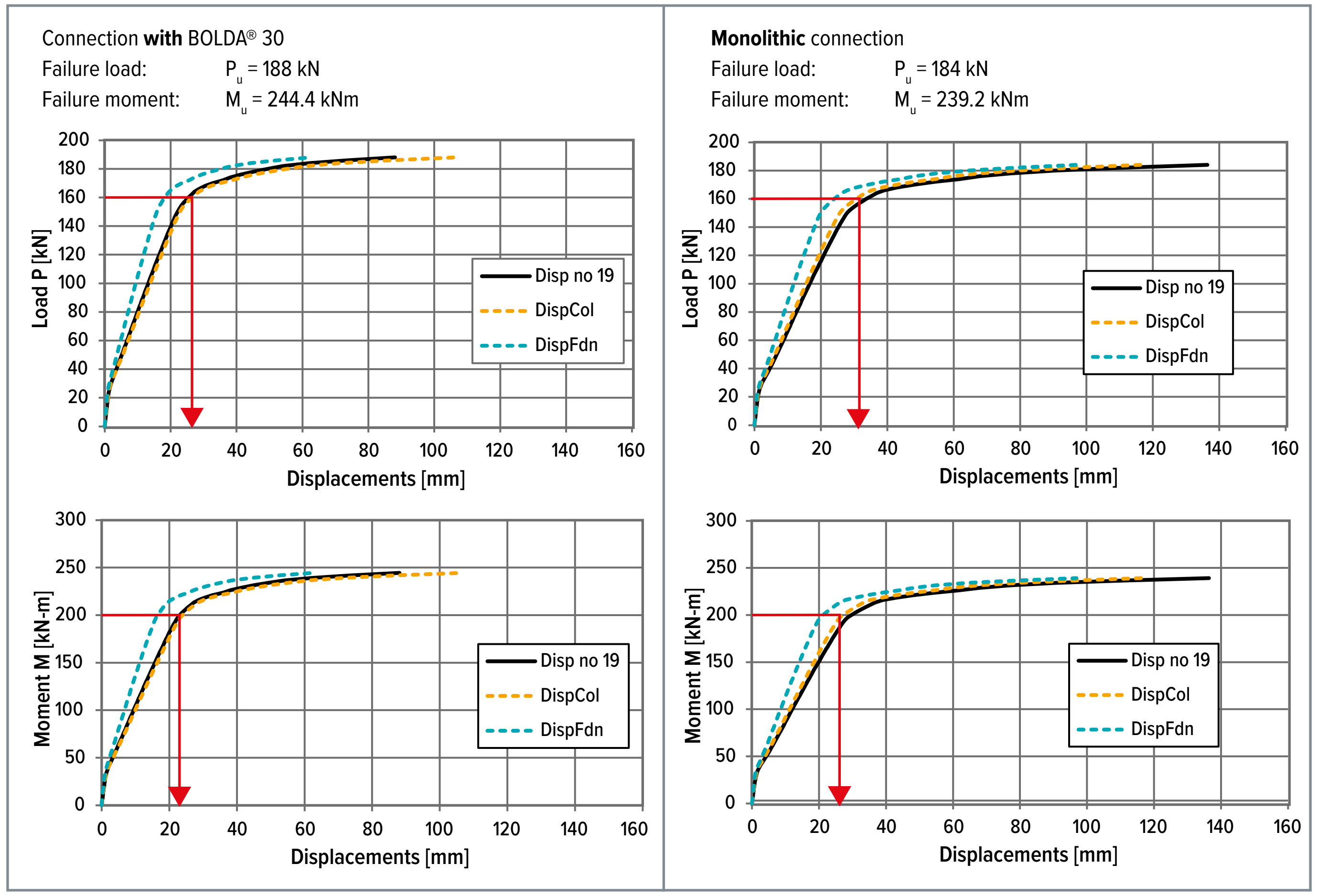



FIGURE 14: LOAD/MOMENT-DISPLACEMENT BEHAVIOR – CONNECTION WITH BOLDA® 30 COMPARED TO MONOLITHIC CONNECTION [18]

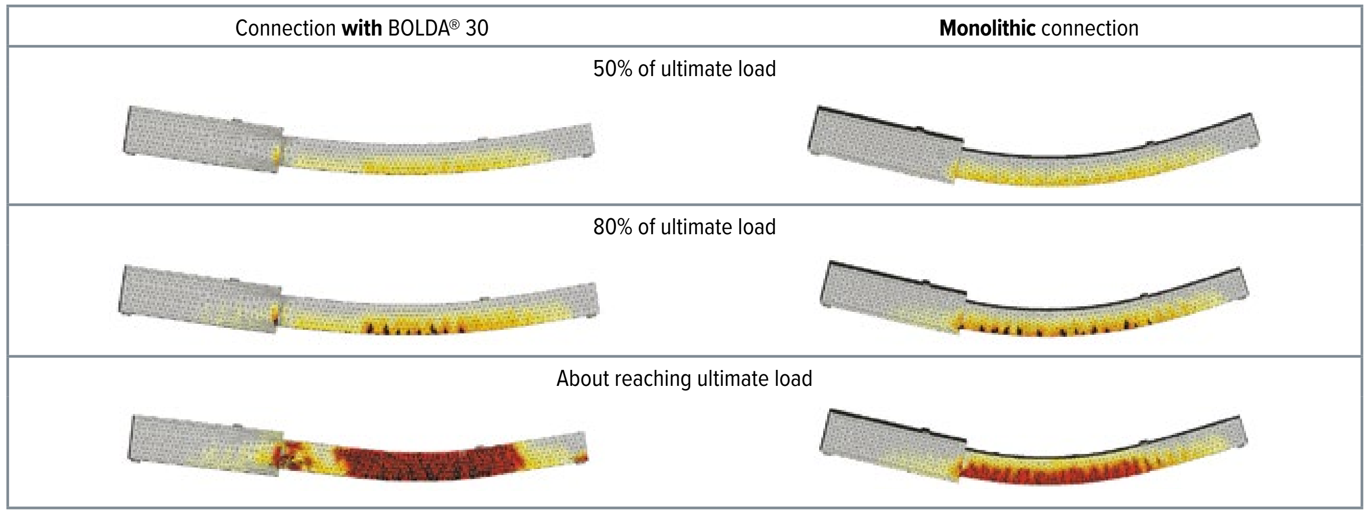
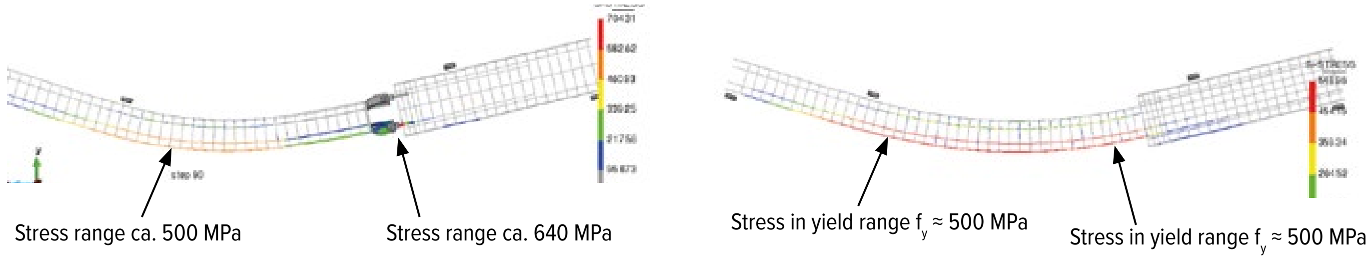



FIGURE 15: CRACK PATTERN COMPARED TO MONOLITHIC CONNECTION [18]




A) COLUMN SHOE SYSTEM

B) MONOLITHIC SYSTEM

FIGURE 16: STRESS DISTRIBUTION WITHIN THE ANCHOR BOLTS, COLUMN SHOE AND REINFORCEMENT AT FAILURE, BOLDA® 30 [18]

The ultimate stage of the column shoe system is characterized by yielding of the PPM® bolts (Figure 16 a). At this stage, the stress in the reinforcement outside of the column shoe area is in the range of σ ≤ 500 MPa. Within the monolithic system, at the ultimate failure load, the maximum stresses occur within the reinforcement in the column area between the end of foundation and the loading point (see Figure 16 b).

Figure 17 and Figure 18 show the corresponding results for the calculations using BOLDA® 52. In total, the results of the calculations confirm the above-mentioned findings and correlations regarding failure load, failure mode and deflections.

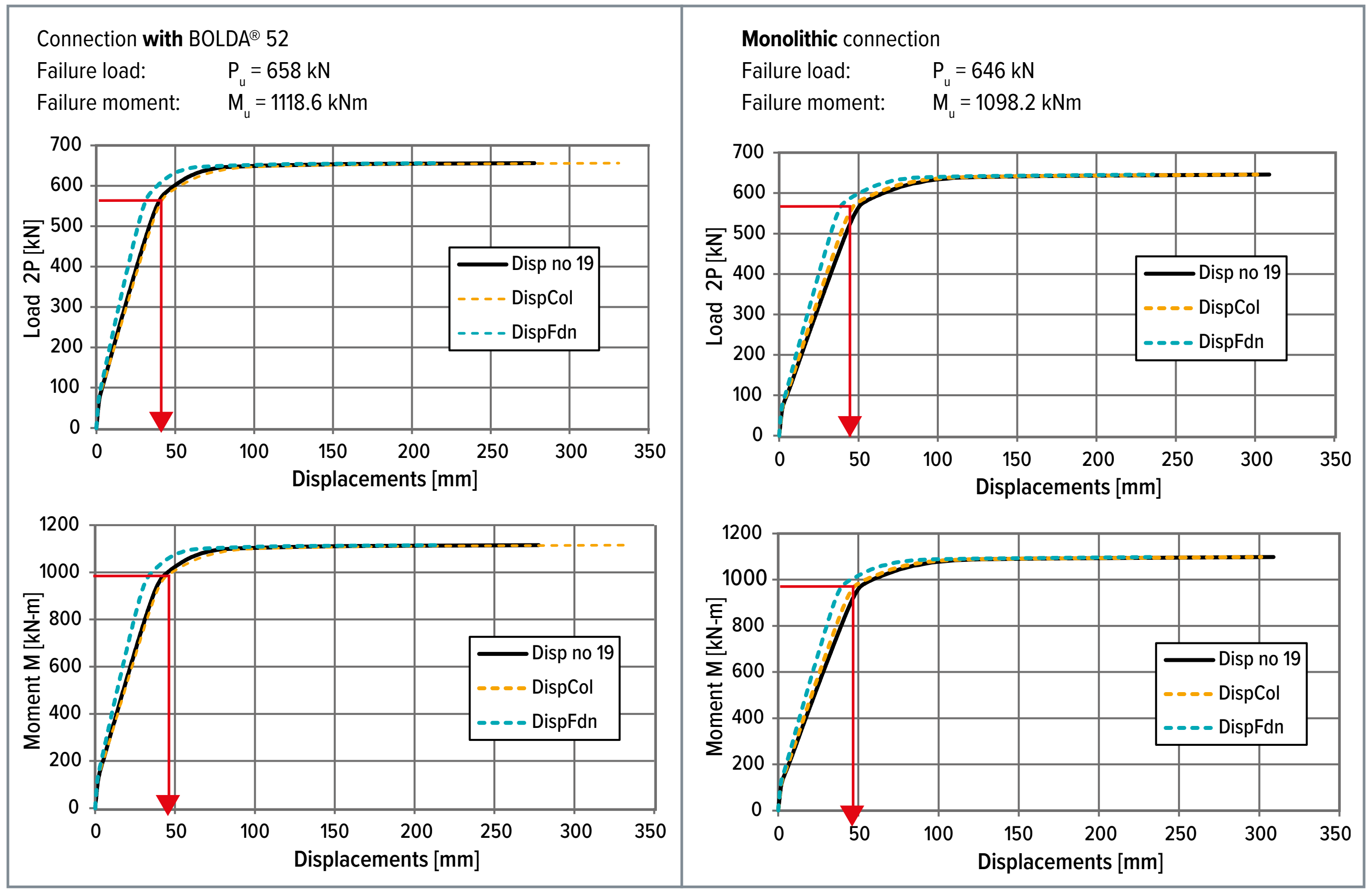



FIGURE 17: LOAD/MOMENT-DISPLACEMENT BEHAVIOR – CONNECTION WITH BOLDA® 52 COMPARED TO MONOLITHIC CONNECTION

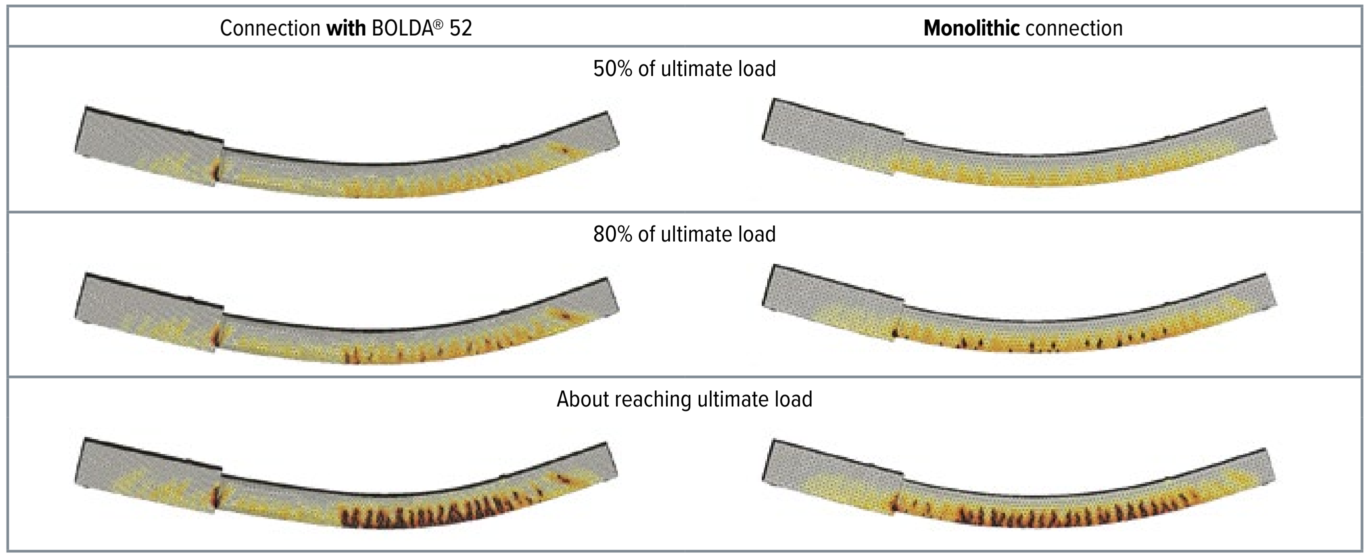
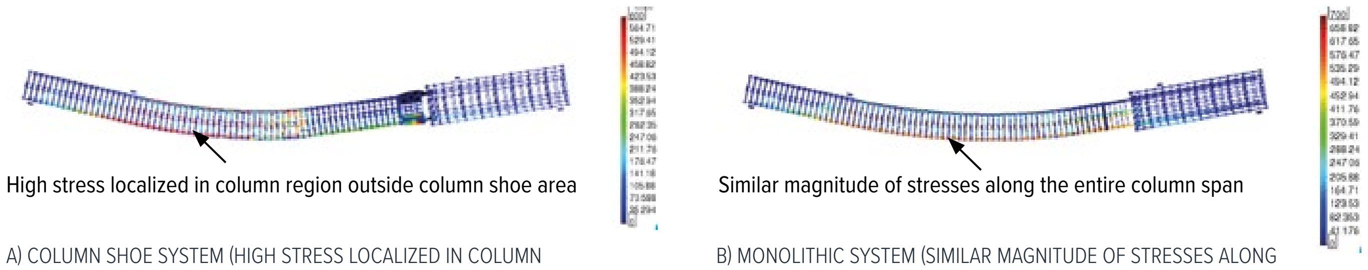



FIGURE 18: CRACK PATTERN COMPARED TO MONOLITHIC CONNECTION [18]




A) COLUMN SHOE SYSTEM (HIGH STRESS LOCALIZED IN COLUMN REGION OUTSIDE COLUMN SHOE AREA)

B) MONOLITHIC SYSTEM (SIMILAR MAGNITUDE OF STRESSES ALONG THE ENTIRE COLUMN SPAN)

FIGURE 19: STRESS DISTRIBUTION WITHIN THE ANCHOR BOLTS, COLUMN SHOE AND REINFORCEMENT AT FAILURE, BOLDA® 52 [18]

| | BOLDA® 30 | | | BOLDA® 52 | | |
|---|---|---|---|---|---|---|
| Subzone i | $M_i$ | Column A | Column B | $M_i$ | Column A | Column B |
| | | $(EI)_i$ | $(EI)'_i$ | | $(EI)_i$ | $(EI)'_i$ |
| | kNm | [MNm²] | [MNm²] | kNm | [MNm²] | [MNm²] |
| 7 | 90 | 18.30 | 18.07 | 412 | 147.05 | 142.95 |
| 6 | 181 | 23.80 | 15.23 | 835 | 184.00 | 128.37 |
| 5 | 188 | 29.60 | 15.56 | 872 | 233.57 | 120.10 |
| 4 | 200 | 28.77 | 15.48 | 923 | 224.66 | 114.66 |
| 3 | 211 | 29.61 | 12.66 | 973 | 248.73 | 136.18 |
| 2 | 222 | 27.33 | 8.76 | 1023 | 220.30 | 146.80 |
| 1 | 234 | 8.73 | 4.41 | 1073 | 102.57 | 79.68 |
| $1.0 \cdot M_{t,0}$ | 239 | | | 1098 | | |
| Deflection | | $v_{shoe}$ | $v_{ref}$ | | $v_{shoe}$ | $v_{ref}$ |
| | | [mm] | [mm] | | [mm] | [mm] |
| | | 77 | 129 | | 172 | 226 |
| $v_{shoe}/v_{ref}$ | 0.61 | | | 0.76 | | |

TABLE 5: COMPARISON OF BENDING STIFFNESSES IN DIFFERENT SUBZONES AND CALCULATED DEFLECTIONS AT THE TOP OF THE COLUMNS – EVALUATION OF FE-RESULTS [18]

The ultimate stage of the column shoe system is characterized by yielding of the PPM® bolts (Figure 19 a). At this stage, the stress in the reinforcement outside of the column shoe area is in the range of σ ≤ 500 MPa. Within the monolithic system, at the ultimate failure load, the maximum stresses occur within the reinforcement in the entire column area between the end of foundation and the loading point (see Figure 19 b).

The bending moment in each subzone and the related stiffnesses in the middle of each subzone, as well as the maximum bending moment at the bottom of the column are calculated according to the procedure described in the previous section. The results are summarized in Table 5.

Figure 20 and Figure 21 show the distribution of the bending stiffness along the column axis related to the bending stiffness of the undisturbed region (subzone 7). In zone 2, the stiffness of precast column A is for both sizes of BOLDA® column shoes significantly higher compared to the cast-in-situ columns. In Zone 3, the relative stiffness of precast column A is smaller than the value obtained for column B. Nevertheless, the higher stiffness of zone 2 will compensate for the lower stiffness in zone 3.

The calculated deflection at the top of the columns based on the measured deformations are $v_{shoe}$ = 77 mm (BOLDA® 30) and $v_{shoe}$ = 172 mm (BOLDA® 52). These values are ca. 39% (BOLDA® 30) and 24% (BOLDA® 52) lower than the reference values of the cast-in-situ columns. Therefore, the results of the FE calculations confirm the test results. Thus, such FE-models are perfectly suited **to support the development of future column shoe systems** both quickly and efficiently. In addition, detailed parameter studies can be carried out.

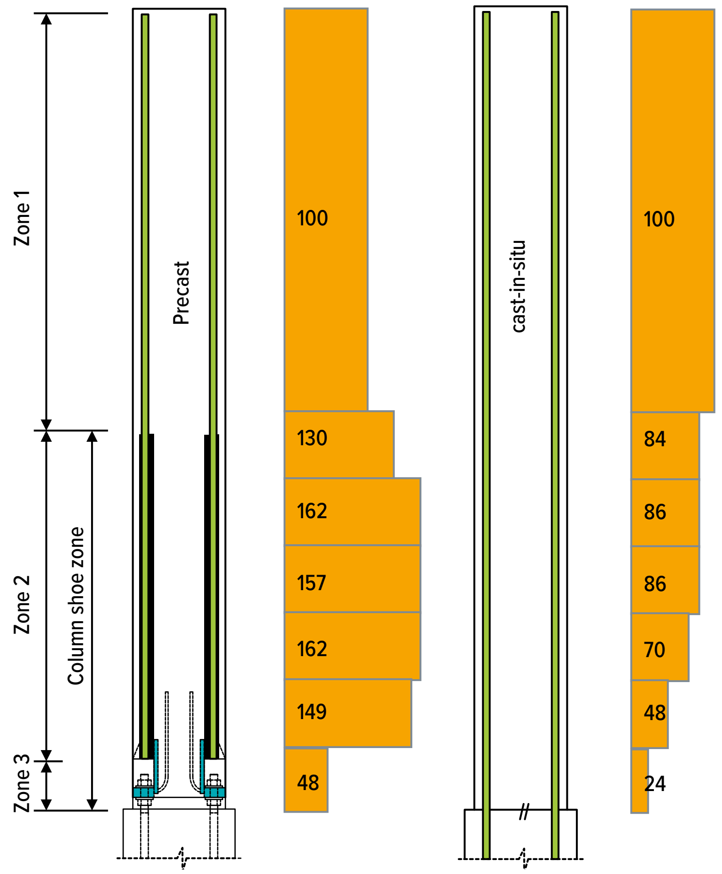



FIGURE 20: EVALUATION OF FE RESULTS FOR COLUMNS A (BOLDA® 30) AND B – RELATIVE BENDING STIFFNESS OF SUBZONES IN %

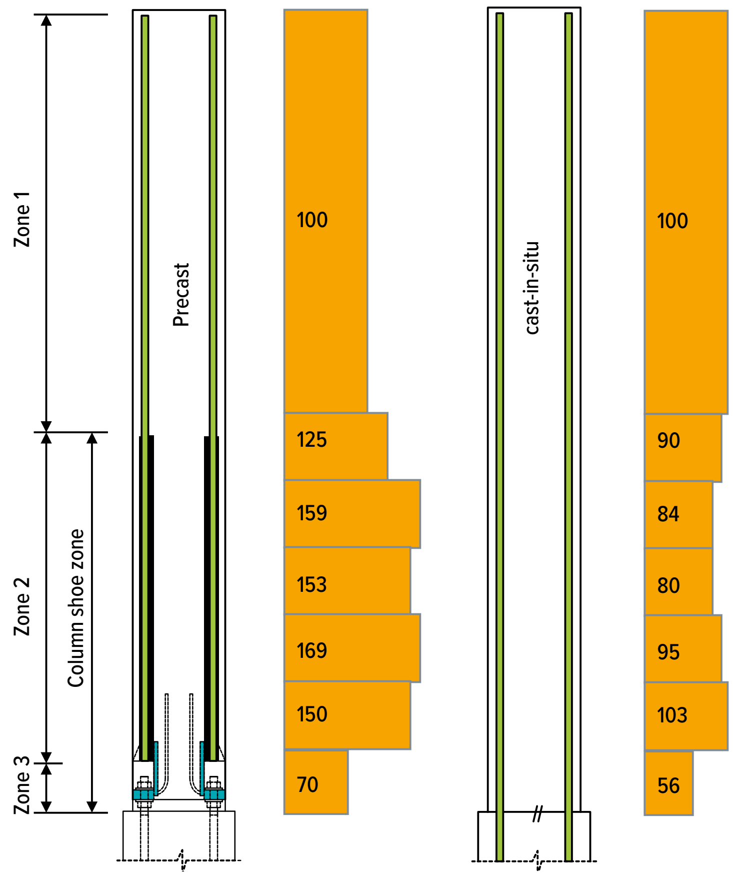



FIGURE 21: EVALUATION OF FE RESULTS FOR COLUMNS A (BOLDA® 52) AND B – RELATIVE BENDING STIFFNESS OF SUBZONES IN %

**FIRE RESISTANCE**

To determine temperatures in case of fire, fire tests on 3 test specimens (BOLDA® 30, BOLDA® 39 and BOLDA® 52) have been conducted at Technical University of Kaiserslautern [12, 13]. In addition, fire simulations using finite element method (FEM) were carried out on five column shoe sizes.

The temperatures determined should serve as a basis for design in the event of fire. The determination of the temperature is based on TR 068 [2]. The results of the fire tests [12] are compared with the results of the FEM simulation [13], and the respective temperatures in case of fire are derived at the critical points of the connection after 30, 60, 90, and 120 minutes of fire duration.

The specimens under consideration consist of a reinforced concrete column connected to a reinforced concrete foundation by means of BOLDA® column shoes and PPM® anchor bolts. The geometry of the test specimens for the fire tests, as well as the FE analysis is shown schematically in Figure 22. The measuring points in the tests correspond to those shown in Figure 22. These measuring points TE14 and TE15 were used for further evaluation.

The dimensions of the column and the foundation, the thickness of the joint, and the combination of column shoes and anchor bolts are given in Table 6. The dimensions of the columns and foundations correspond to the respective required minimum values.

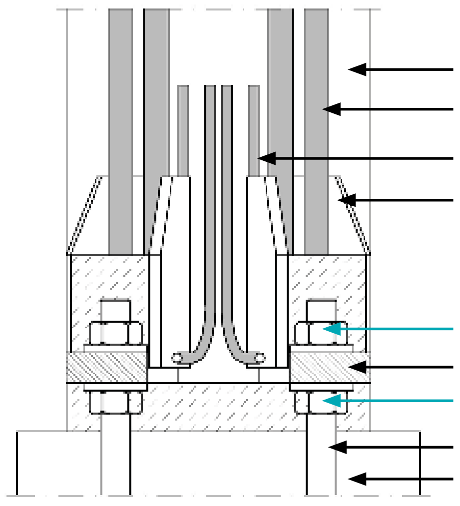
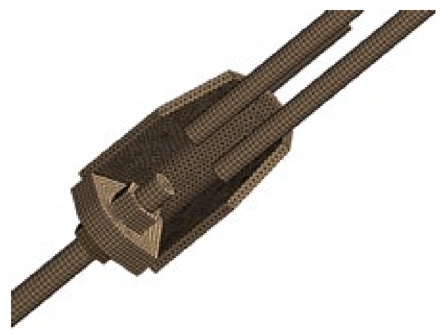



FIGURE 22: OVERVIEW OF THE CRITICAL SECTION

| Column shoe | Anchor bolt | Column | Foundation | Joint thickness |
|---|---|---|---|---|
| | | mm x mm | mm x mm | mm |
| BOLDA® 30 | PPM 30 P | 310 x 310 | 410 x 410 | 50 |
| BOLDA® 36 | PPM 36 P | 360 x 360 | 460 x 460 | 55 |
| BOLDA® 39 | PPM 39 P | 390 x 390 | 490 x 490 | 60 |
| BOLDA® 45 | PPM 45 P | 450 x 450 | 550 x 550 | 65 |
| BOLDA® 52 | PPM 45 P | 500 x 500 | 600 x 600 | 70 |

TABLE 6: SIZES OF COLUMN SHOE AND ANCHOR BOLTS AND CORRESPONDING MINIMUM CONCRETE SECTIONS [12]

A) COMPLETE SPECIMEN



B) BOLDA® 30 COLUMN SHOE AND ANCHOR BOLT PPM® 30 P

FIGURE 23: EXAMPLE OF THE FINITE ELEMENT MODEL [13]

The column connection was subjected to thermal stress using the standard fire curve according to DIN EN 1363-1 [16]. The test setup within the fire chamber is shown in Figure 24. Test specimens after completion of the fire tests are shown in Figure 25. It can be clearly seen that the greatest damage in the form of concrete spalling occurs at the points with the highest heat input, and at the same time with the smallest concrete volume – i.e. at the corners of the columns. It is important to note that no damage occurs in the area of the column shoe connection.

The results of the finite element calculation are summarized in [13]. Figure 26 shows exemplarily the results for BOLDA® 39 after a duration of 120 min.

Figure 26 clearly indicates that the maximum temperature appears on the outer faces of the column shoe base plate and the lower area of the side plate. The highest temperature of the anchor bolt is inside the base plate.

The comparatively lower temperatures in the anchor bars and the rear bars indicate that the fire resistance of the entire system is predominantly influenced by the temperature in the anchor bolt at the level of the anchor plate nearby the anchor bolt.

For all connections, the calculated temperature of anchor bolt section, as well as the measured temperature of tested anchor bolts, all at time points 30, 60, 90, and 120 minutes, are evaluated. Next, the difference between the **measured** temperatures and **calculated** temperatures at TE14 or TE15 is calculated for BOLDA® 30, BOLDA® 39, and BOLDA® 52.

FIGURE 24: TEST SPECIMENS IN THE COMBINED FIRE FURNACE AND ARRANGEMENT OF THE FURNACE THERMOCOUPLES [12]

FIGURE 25: TEST SPECIMENS AFTER COMPLETION OF THE FIRE TESTS

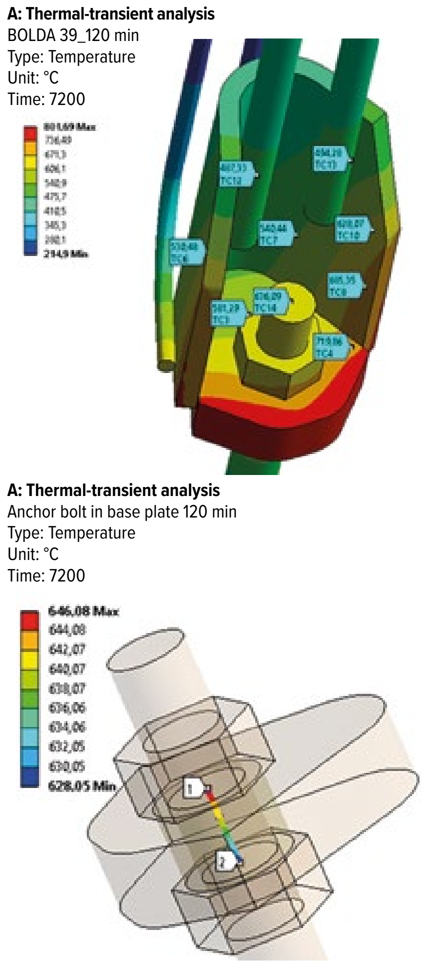



FIGURE 26: TEMPERATURE DISTRIBUTION IN COLUMN SHOE BOLDA® 39 AFTER 120 MIN [13]

| Time | BOLDA® 30 | BOLDA® 36 | BOLDA® 39 | BOLDA® 45 | BOLDA® 52 |
|---|---|---|---|---|---|
| min | °C | °C | °C | °C | °C |
| 30 | 206 | 171 | 182 | 178 | 147 |
| 60 | 387 | 336 | 349 | 340 | 293 |
| 90 | 530 | 475 | 488 | 470 | 412 |
| 120 | 641 | 588 | 594 | 571 | 508 |

TABLE 7: RESULTING TEMPERATURES FOR FIRE DESIGN OF BOLDA® COLUMN SHOE CONNECTIONS

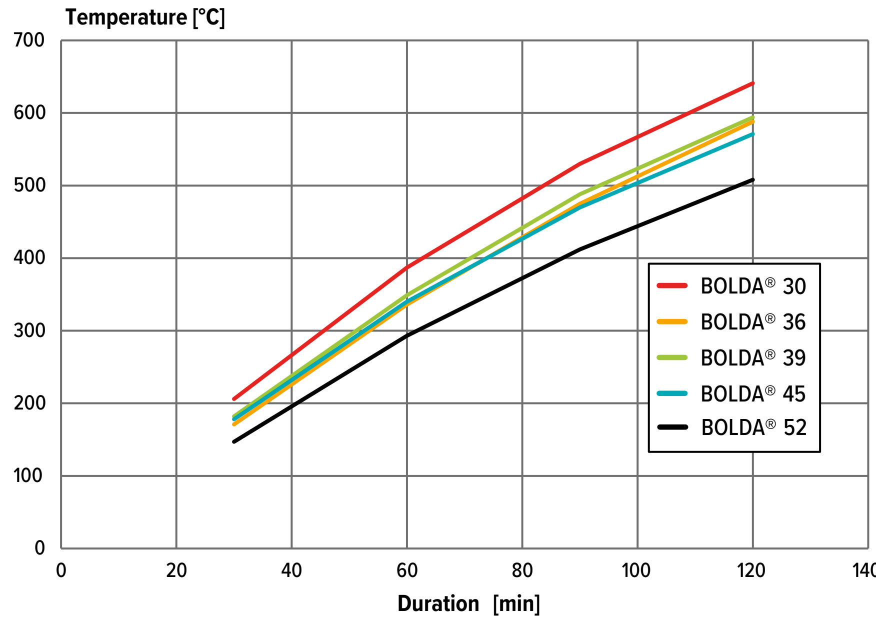



FIGURE 27: TIME-TEMPERATURE CURVES AT THE ANCHOR BOLT OF BOLDA® COLUMN SHOE CONNECTIONS [14]

The mean value of the mean differences is then calculated from the differences at the TE14 and TE15 positions. The mean difference between **the test results** and the **results of the FE calculation** determined in this way enable the calculation of the temperature in the anchor bolt at the level of the base plate below the upper nut. Therefore, the temperature of the bolt from the FEM simulation is reduced by the mean difference. For the BOLDA® 36 and 45 column shoes, this is done using the mean value of the neighboring column shoe sizes. The resulting temperatures are given in Table 7 and visualized in Figure 27. Table 7 and Figure 27 show that with increasing size of the column shoes in general the resulting temperature in the bolt decreases. For the three intermediate sizes this effect is less pronounced.

## SUMMARY OF THE TEST RESULTS

The evaluations of the test results in the sections above clearly indicate that the design methods for column shoe connections given in the EAD are valid for BOLDA® column shoes. Furthermore, it was shown that the load bearing behavior, as well as the deformations of a precast column containing BOLDA® column shoes do not differ from the behavior of cast-in-situ columns of the same dimensions and reinforcement layout.

BOLDA® column shoes and column connections fulfil all requirements according to EAD regarding mechanical, fire, and corrosion resistance. Design of column connections with BOLDA® column shoe connections is included in Peikko Designer® to facilitate daily tasks of structural engineers.

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