PEIKKO

WHITE PAPER

TALL BUILDING SOLUTIONS

INTRODUCTION

Tall Buildings are a product of our time and a globally accepted solution to densification, lack of land, growing population and reducing commute time.

Although Tall Buildings play an important role in modern society, this type of construction presents unique challenges for all parties involved in their design and construction. With over 50 years of experience in building design of all heights, Peikko can help stakeholders to make their next Tall Building more efficient to build and operate.

This document will explain best practices of Peikko's products and solutions in Tall Buildings from all over the world.

1 DEFINITION OF TALL BUILDING

High-Rise Building, Tall Building and Multi-story Building – are different terms having one meaning.

The Council on Tall Buildings and Urban Habitat mention height relative to context, proportions and tall buildings' embracing technologies as criteria which can determine whether the building can be classified as a "Tall Building" [1].

> "If a building can be considered as subjectively relevant to one or more of the above categories, then it can be considered a tall building. Although number of floors is a poor indicator of defining a tall building due to the changing floor-to-floor height between differing buildings and functions (e.g. office versus residential usage), a building of 14 or more floors – or more than 50 meters (165 feet) in height – could typically be used as a threshold for a "tall building."
>
> (The Council on Tall Buildings and Urban Habitat)

FIGURE 1 CTBUH HEIGHT CRITERIA THAT CAN HELP IN CLASSIFICATION OF THE BUILDING [1]

2 DRIVING ASPECTS IN TALL BUILDING DESIGN

As a building grows taller, the vertical loads increase with the height of the building. At the same time, horizontal loads start to increase rapidly and significantly affect the Tall Building. Under lateral loading, the building behavior can be compared to a cantilever beam with its base fixed in the ground. When wind loads are acting on the top level of the building, a significant moment is generated at the base of the structure (Figure 2). The columns on the side where the wind load is applied are subject to tension forces, while the columns on the opposite side of the building are subject to compression forces. Therefore, Tall Buildings must have adequate shear and bending resistance and must not lose vertical load-bearing capability.

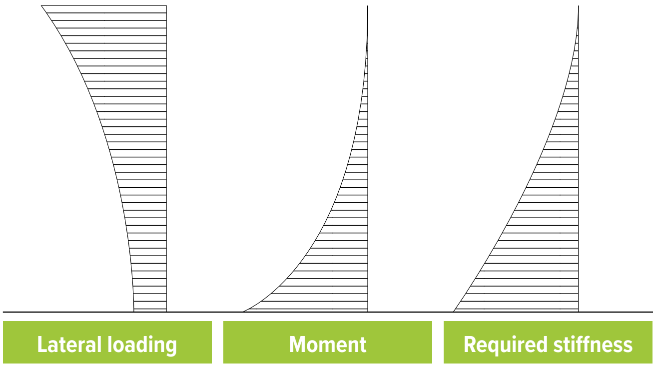


FIGURE 2 WIND LOAD, MOMENT, AND STIFFNESS DIAGRAM FOR A TALL BUILDING

Worldwide Tall Building design practices are different and might be governed by a combination of gravitational, wind and seismic loads, depending on the local building code. The design for a Tall Building in Tokyo will likely be governed by seismic loads, while the design for a building in Copenhagen – by wind loads. Lateral loads of seismic forces increase in direct proportion to acceleration of ground motion and the mass of the building. If the ground motion acceleration or the building mass is doubled, the horizontal force will be doubled as well.

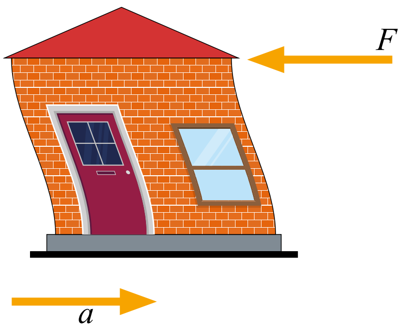


FIGURE 3 NEWTON'S SECOND LAW OF MOTION, WHERE "F" IS INERTIA FORCE AND "A" IS ACCELERATION

Unfortunately, the structural design of a Tall Building is not as simple as described in Newton's Law, and it contains many additional variables and considerations to be solved. But no doubt the main design objective is adequate lateral stiffness of the building. In principle it would require a structural engineer to satisfy two serviceability criteria – lateral deformation (deflection, drift) and motion perception (acceleration, vibration). Satisfying the first means limiting the maximum lateral displacement at the top of the building and inter-story drifts separately. For a total drift of the building, there is a commonly used drift index that is expressed as ratio of the maximum deflection at the top floor of the building to the total height of the building. Even though many international design codes do not apply limits on total lateral deflection of the building, the rule of thumb for the limit is between h/400 and h/600. The main purpose of controlling deflection is enabling non-structural elements of the building to function properly. Practical ways of limiting drift can be to increase the bending stiffness of the horizontal members, adding stiffeners like shear walls or core, or even designing stiffer connections.

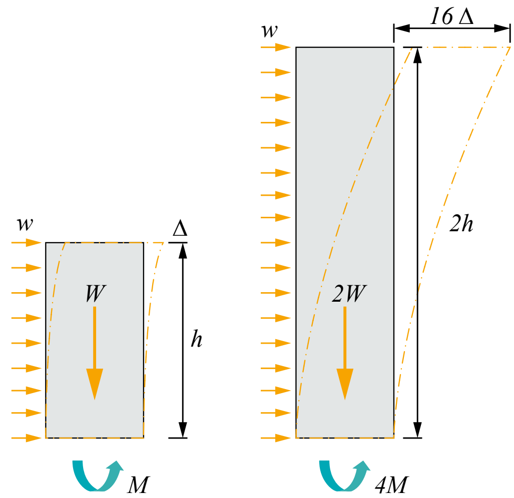


FIGURE 4 LATERAL DEFLECTION DIAGRAM OF SHORTER AND TALLER BUILDINGS

The second criteria is ensuring the occupant's comfort level, which is dictated by the amount of wind induced movement. Tall Buildings can be allowed to sway considerably, but the acceleration (the rate at which its movement increases) must be damped within acceptable limits. Those limits are based on the sensitivity of our inner ear to motion. Since humans are more sensitive to motion when lying down, residential buildings typically allow less acceleration than commercial office buildings. Acceleration can be damped in different ways, including stiffer structure or sometimes with the use of supplementary damping such as Tuned Mass Dampers. A Tuned Mass Damper limits the horizontal acceleration by mechanically shifting a large mass in the opposite direction of the applied lateral forces.

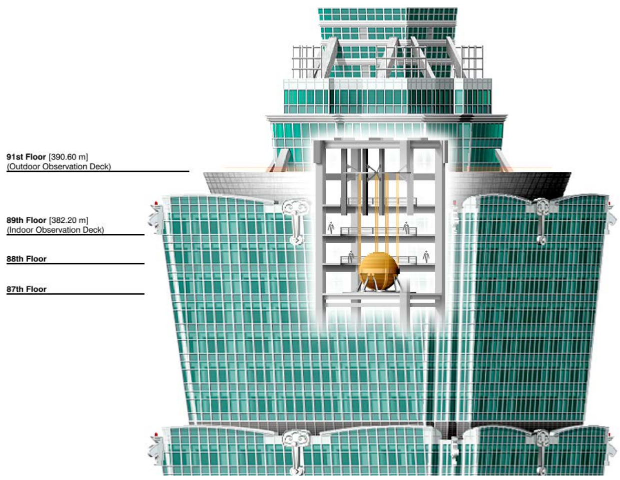


FIGURE 5 THE TUNED MASS DAMPER IN TAIPEI 101 [2]

3 STRUCTURAL SYSTEMS OF TALL BUILDINGS

Strength, lateral stability and rigidity are the main requirements for the structural design of Tall Buildings.

For decades, structural engineers all around the world have been improving the performance and efficiency of lateral stability systems through countless iterations and with the ever-increasing help of structural design softwares.

Moving major resisting structure from perimeter towards the interior of the building, wrapping the building into a diagrid web, splitting the building into several tubes standing next to each other – these are just some examples of structural systems' evolution, which are still valid nowadays, but used in more comprehensive ways. The most common classification to describe Tall Building structural systems is shown in Figure 6.

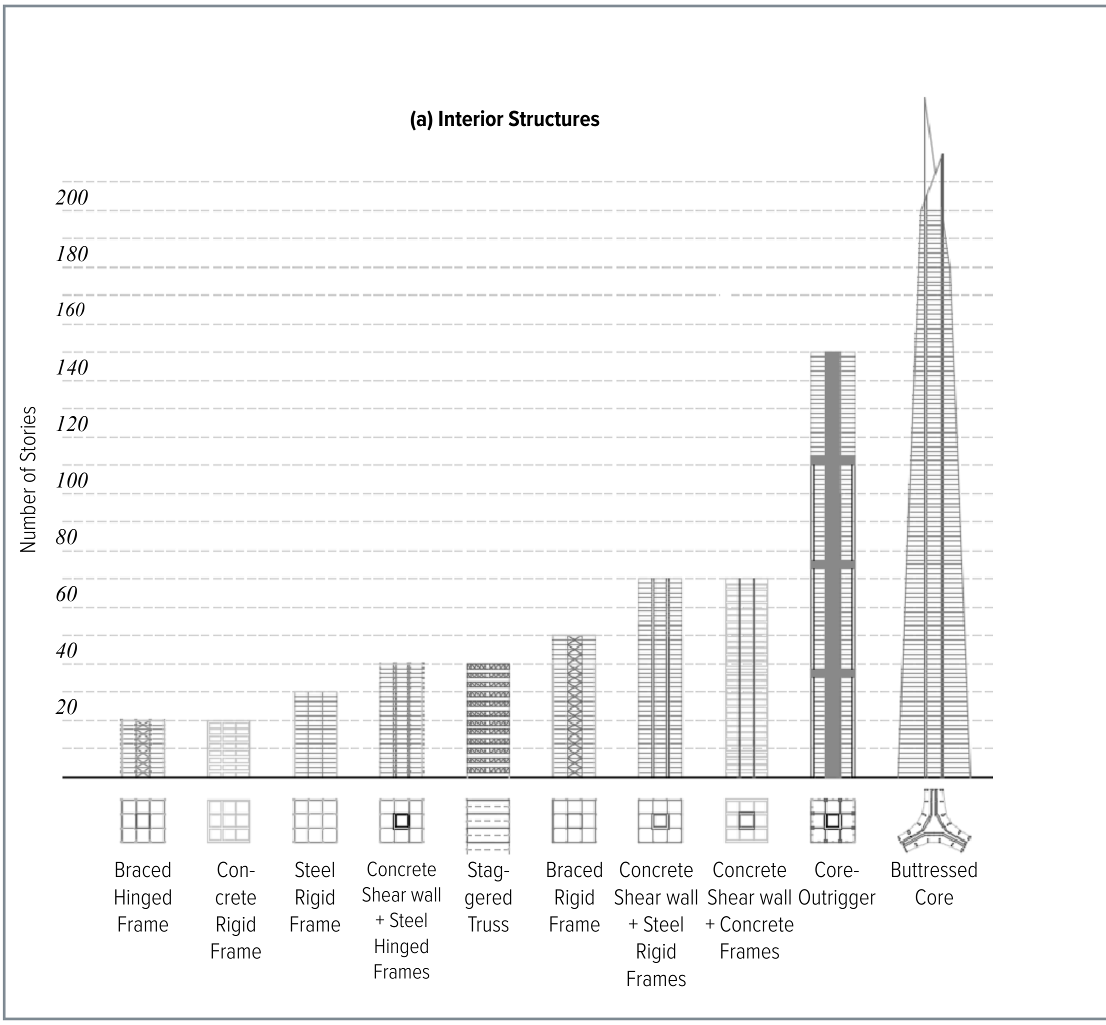


FIGURE 6 CLASSIFICATION OF TALL BUILDING STRUCTURAL SYSTEMS BY MIR M. ALI AND KYOUNG SUN MOON [3]

One of the first structural systems from which other systems started to evolve was a rigidly jointed structural frame. The core idea was to place as much vertical load-carrying elements as possible on the periphery of the building to maximize its ability to resist angular acceleration. The angular acceleration resistance of a building can be explained by Newton's 2nd Law - $\alpha=\frac{\sum\tau}{I}$, where α is an angular acceleration, $\sum\tau$ – a net torque and I – a moment of inertia. A structural system that has large moment of inertia will resist acceleration more easily. An effective way to increase the moment of inertia is to move the mass away from the center of the building ($I=mr^2$, where m is a point mass and r^2 is a radius from the axis squared).

Rigid frames, also called moment resisting frames, typically consist of beams and columns connected by rigid joints that minimize relative rotation between the two structural components. In this system, both gravity and lateral loads are resisted by the bending action of the main frame elements i.e. beams and columns. Lateral stiffness of the entire frame is dependent on the bending stiffness of its elements.

As seen in Figure 8, rigid or moment-resisting frames have bigger deflection and drift than the shear walls. Each of the above-mentioned structures have strengths and weaknesses. To overcome shortcomings

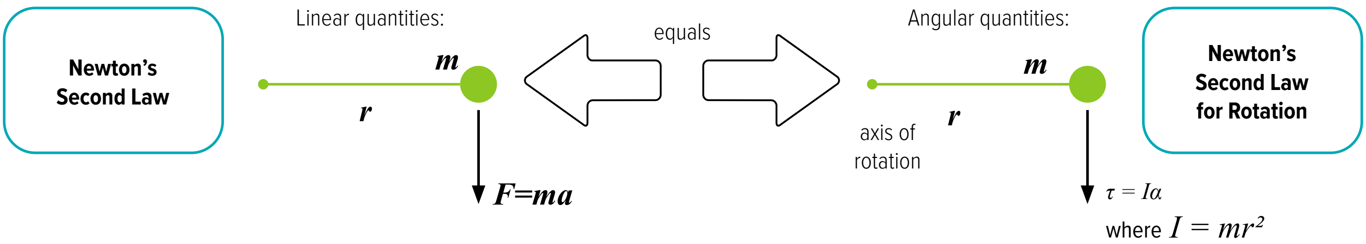
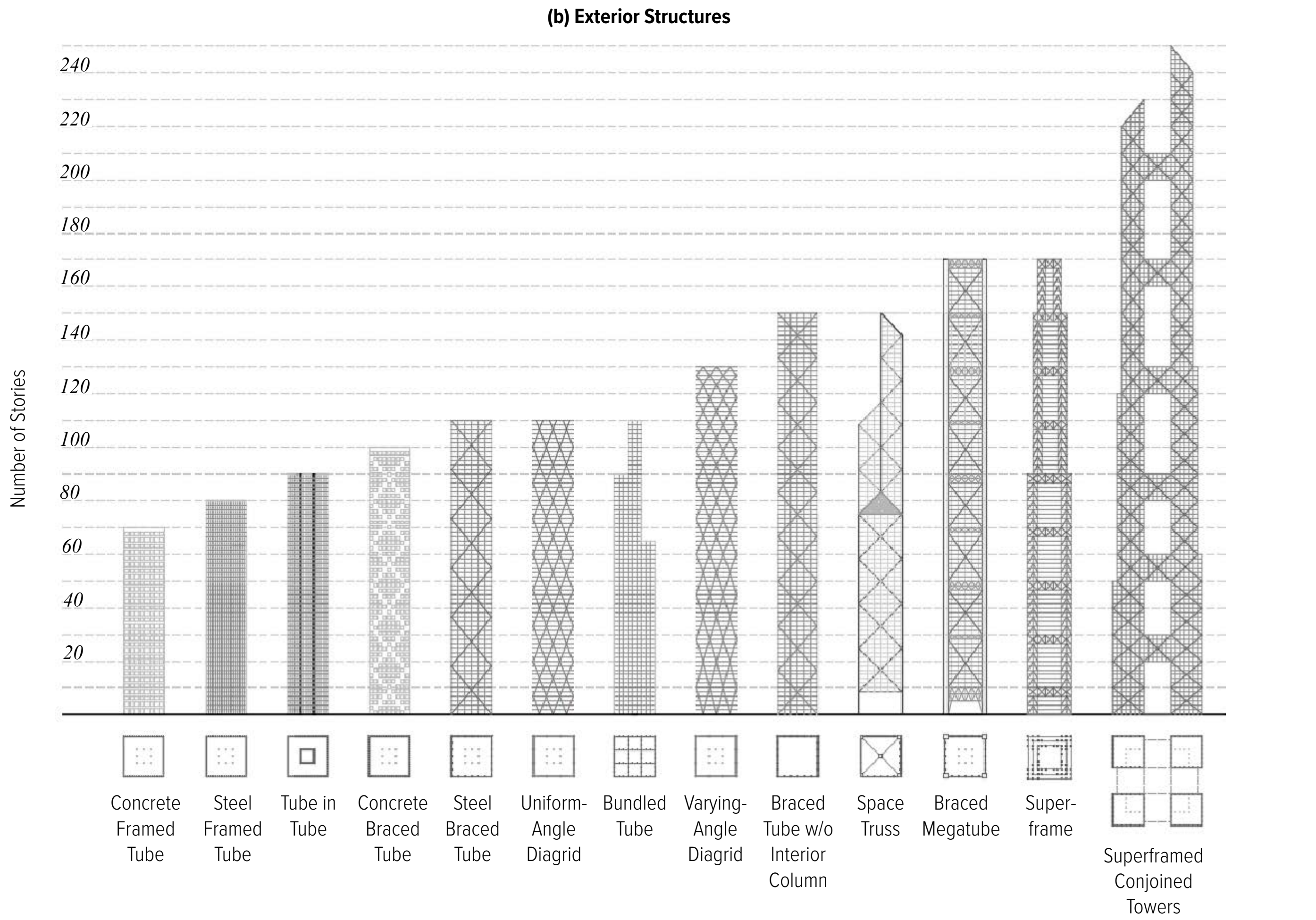


FIGURE 7 VISUALIZATION OF NEWTON'S SECOND LAW FOR ROTATION



of a single structural system, a natural idea is integrating strengths of different systems to obtain desired behavior of the Tall Building. Rigid frames are economical for buildings roughly up to 25-30 floors, above which their drift resistance is costly to control. If, however, a rigid frame is combined with shear wall system, the resulting structure becomes much stiffer, enabling the building to rise roughly up to 60-70 floors. To reach Super Tall Building's reference mark, the resulting structure generally has to be more complex than just the combination of two above-mentioned systems.

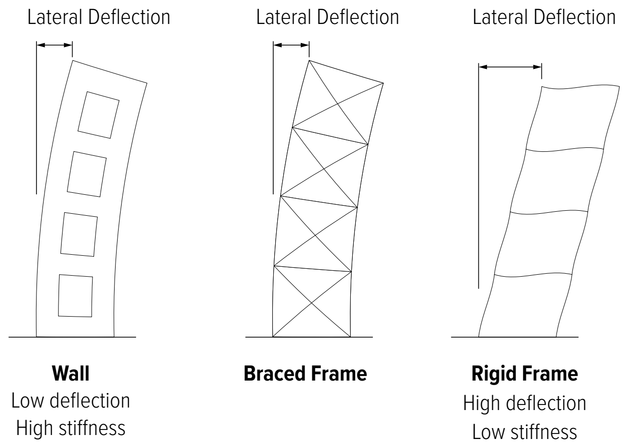


FIGURE 8 CHARACTERISTICS OF RIGID, BRACES FRAMES AND WALL SYSTEM

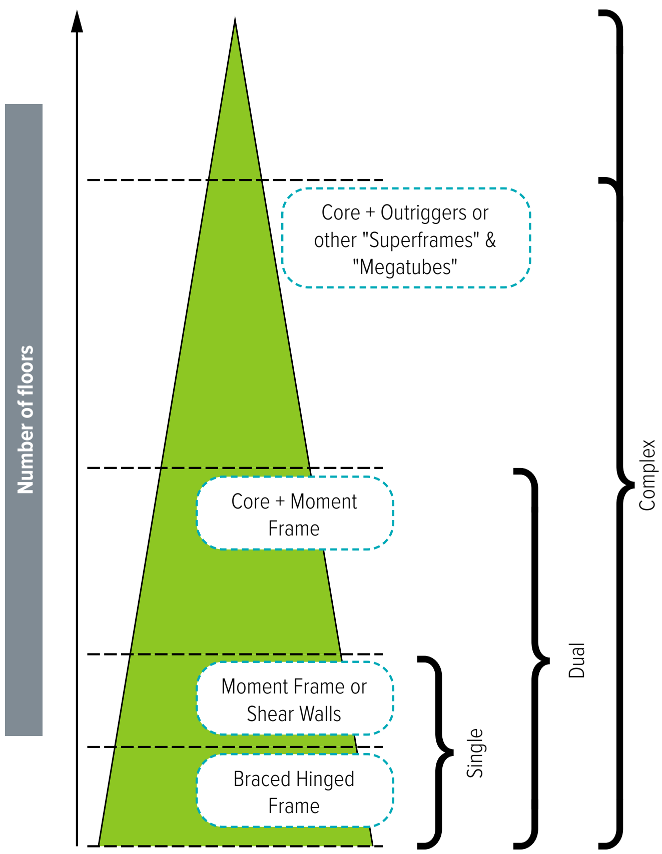


FIGURE 9 SCHEMATIC DIAGRAM OF SYSTEM TYPES FOR VARIOUS BUILDING'S HEIGHTS

4 PEIKKO'S PRESENCE IN TALL BUILDINGS

Regardless the structural system chosen by the structural engineer, the connections between elements are vital in every Tall Building. One of the most important aspects of lateral force design is the connections between the structural elements of the building. Over the years, Peikko has developed multiple solutions to simplify the design and installation of connections for securing structural elements together.

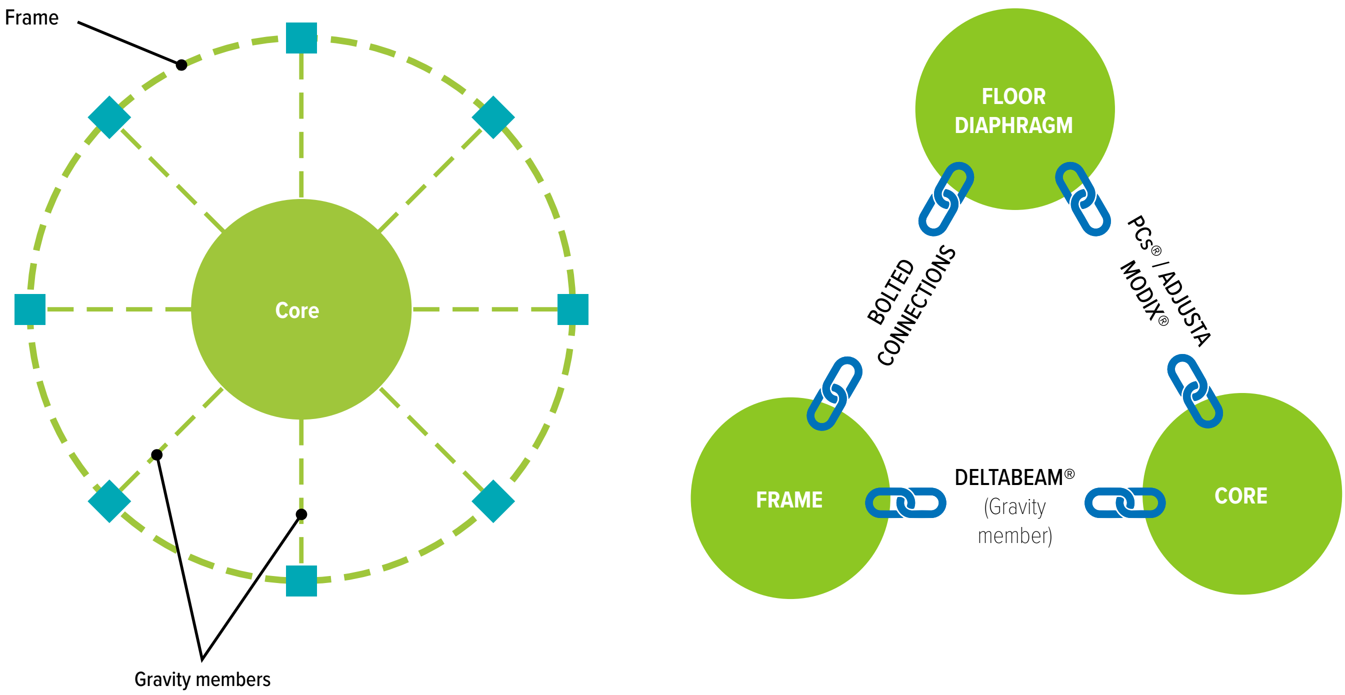
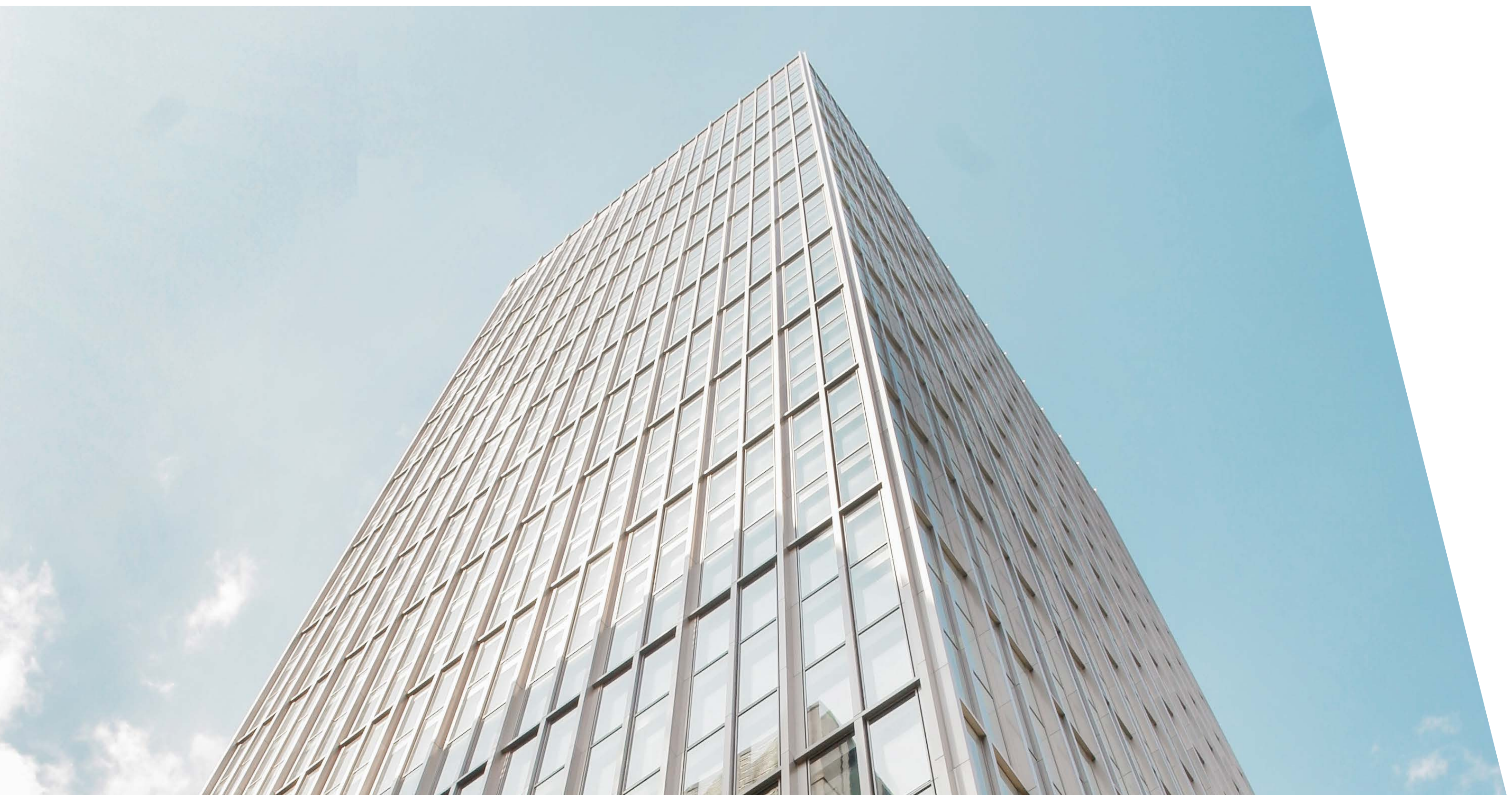


FIGURE 10 SCHEMATIC REPRESENTATION OF SOME PEIKKO'S SOLUTIONS IN TALL BUILDINGS



4.1 OPTIMIZING THE SIZE OF FOUNDATION (EFFICIENT FOOTINGS AND FOUNDATIONS)

MONDE CONDOMINIUMS IN TORONTO, CANADA

Project data:
30 floors
Building type – Residential
Developer – Great Gulf
Construction Company – Tucker Hirise
Structural Designer – RJC (Read Jones Christoffersen)
Architect – Quadrangle Architects
More info – Peikko Canada Inc.

In this project, Peikko's double-headed shear rail system is not tying structural elements together, but contributing to their elements in geometry and construction process. Depending on the market requirements (compliance with local design standards and material standards) you will find PSB® Punching Reinforcement and ARMATA® Punching Reinforcement in Peikko's portfolio. The purpose of such shear rail systems is to prevent punching shear failure in flat slabs. The same solution works for foundations, beams and even walls. Monde, a high-rise project in Toronto, in particular is using a shear rail system in the foundation walls of five-level underground parking. Kumbo Mwanang'onze from RJC Consulting Engineers is the head structural engineer for Monde. "The underground parking proved to be a challenge due to the earth pressure applying high shear forces on foundation walls'' he explains. ''Earth density is usually 2000 kg per cubic meter. In the presence of ground water, the pressure on foundation walls rises considerably, increasing the shear force on walls at either side of the slabs'' points out Mwanang'onze. Because this site is located directly adjacent to Lake Ontario, the walls are designed on the assumption of the water-table being at ground surface. For a 5-story underground structure, this pressure creates high shear forces on both sides of each suspended slab. Easy to install stud rails were specifically designed to resist these shear forces. Traditionally, rebar stirrups are used to strengthen foundation walls against shear forces, but they are labor-intensive. Compared to working with rebar stirrups, shear rails greatly reduce onsite manual labor. Installation is simply done with two workers: one hanging stud rails on the wall rebar, another tying the stud rails to the rebar. This solution is not only enabling cost effective construction process, but also improves the design itself. Compared to working with a thickened foundation wall, shear rails make your walls thinner and therefore increase your interior space for parking.

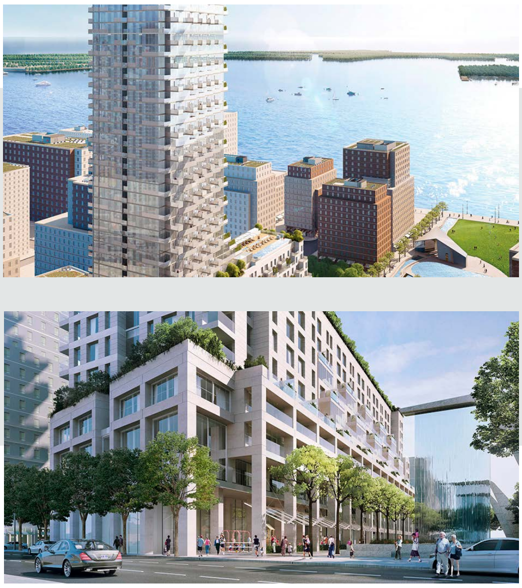


FIGURE 11 MONDE CONDOMINIUMS IN TORONTO

PSB® Punching Reinforcement

ARMATA® Punching Reinforcement

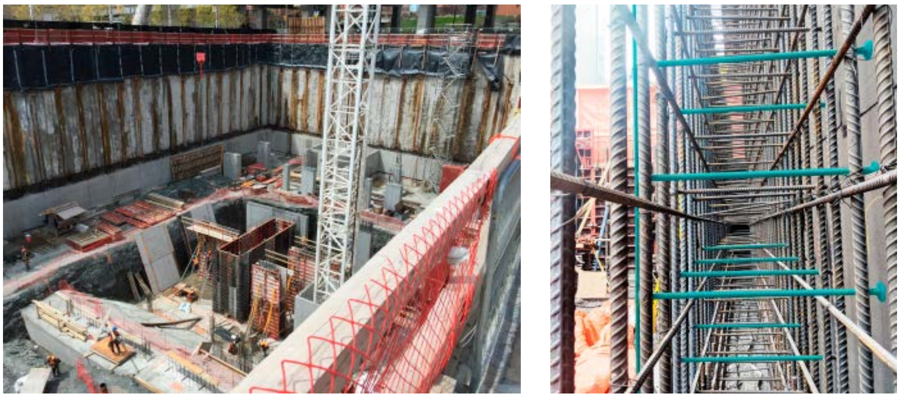


FIGURE 12 MONDE'S UNDERGROUND FOUNDATION WALLS DONE WITH ARMATA® PUNCHING REINFORCEMENT (LEFT). CROSS-SECTION OF THE WALL WITH PEIKKO'S PUNCHING REINFORCEMENT (RIGHT).

FIGURE 13 SIDE VIEW OF THE MONDE'S FOUNDATION WALL

Installation pace was 80 rails per hour with only 2 workers. If we take an average of 10 studs per rail, this is the equivalent of placing and fixing 800 stirrups in one hour with 2 workers.

4.2 REDUCING FLOOR-TO-FLOOR HEIGHT WITH SLIM STRUCTURES

300 MAIN IN WINNIPEG, CANADA

Project data:
142 meters
42 floors
Building type – Commercial and residential
Construction Company – Marwest
Structural Designer – Crosier Kilgour & Partners Ltd.
Architect – Raymond SC Wan Architects
More info – Peikko Canada Inc.

DELTABEAM® Composite Beam

FIGURE 14 300 MAIN IN WINNIPEG © RAYMOND SC WAN ARCHITECTS AND SAFDIE ARCHITECTS

It's no secret that developers want to maximize the number of floors in order to get more rentable space within a certain height allowance. Slim Floor Structures help to address this need very successfully. By reducing the floor plate thickness, floor-to-floor height becomes lower. Which in turn yields more floors for a given building height. 300 Main, a 42-story building on the corner of Main Street and Graham Avenue in Winnipeg, uses the Slim Floor concept as well. A typical floor in 300 Main is a combination of DELTABEAM® Composite Beams and hollow-core slabs. Grout fill is used to tie the beams and slabs together and create composite action on-site. The other option of using hollow-core slabs with wide flange steel beams was also considered for the new tower but this solution would have resulted in a building at least 15m (50 ft) taller, which would have increased the total price of the project significantly. DELTABEAM® Composite Beams instead have saved overall height of the building to add additional floors and maximize the building total square footage.

Another powerful argument in favour of Slim Floors is reduced weight of the overall structure, which in turn makes foundation less expensive. In this case, 300 Main's new tower is using the same foundation pad as 360 Main, an adjacent 30-story tower built in 1979. Since the combination of DELTABEAM®, hollow-core slabs and steel columns is much lighter than 360 Main's cast-in-place structure, the developer was able to increase the number of floors from 30 to 42 using the same foundation pad as the 30 story building.

The added advantage of DELTABEAM® Composite Beams 2-hour fire rating without additional fireproofing also provided substantial savings. The underside of these floors is commonly used as a finished ceiling that is smooth and regular.

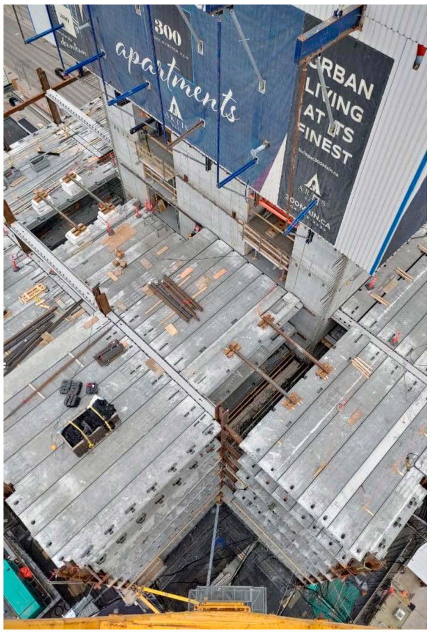


FIGURE 15 LEVEL 21 OF 300 MAIN TOWER. DELTABEAM® AND HOLLOW-CORE SLAB LAYOUT.

GLASSHOUSE IN WINNIPEG, MB, CANADA

Project data:
21 floors
Building type – Residential
Developer – Urban Capital
Construction Company – Bockstael Construction Ltd.
Structural Designer – Crosier, Kilgour & Partners
Architect – Stantec Architecture Winnipeg
Precaster – Haywood
More info – Peikko Canada Inc.

DELTABEAM® Composite Beam

Just as in the previous project, DELTABEAM® Composite Beams have played an important role in meeting the needs of the architect, structural designer and contractor. The architects of the Glasshouse project in Winnipeg were looking for a solution that would incorporate a slab thickness of 9 to 10 inches (roughly 229 to 254 millimeters). DELTABEAM® Slim Floor Structure was the perfect solution, allowing the top and bottom planes to include both the structural floor and the structural beams in a 9-inch-deep system, without the beams projecting below the slab. DELTABEAM® reduced the structural depth of each floor by 16 inches, which translated into 2 extra floors compared to conventional structural technology.

DELTABEAM® Slim Floor Structure allows for a rapid speed of erection due to the prefabrication of slabs and steel frame. DELTABEAM® Composite Beams were connected to the columns using Peikko's modular PCs® Corbels, which were factory-welded to the steel columns to provide lego-like ease of installation. Flat ceilings also meant straightforward HVAC installations that further reduce building time.

An additional bonus at the Glasshouse building site was that DELTABEAM® Composite Beams did not require intumescent coating. Intumescent paint is the standard industry procedure if the steel is exposed, but this has to be done on site. It can also take some time, as you need a primer, base coat and decorative topcoat. None of this was needed with DELTABEAM®, as the beam is cast in concrete. To prove the point, DELTABEAM® was UL-tested to achieve 2-hour, 3-hour and 4-hour ratings with no additional fire protection on the beam.

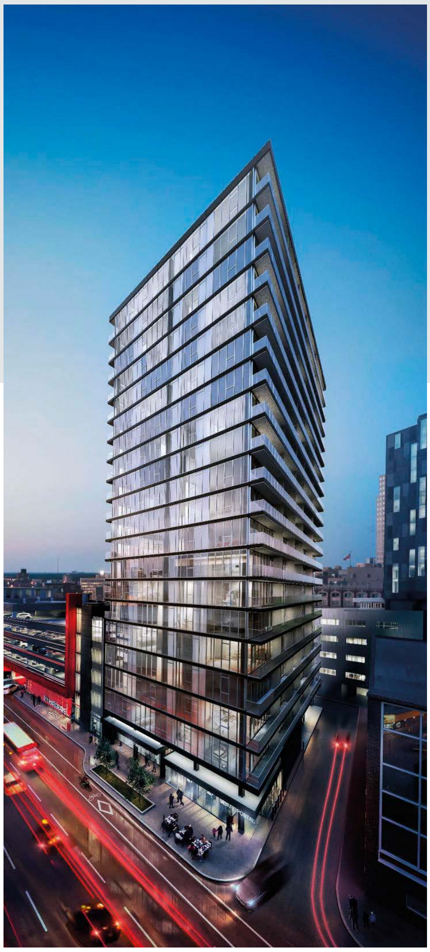


FIGURE 16 GLASSHOUSE

FIGURE 17 SIDE VIEW TO CONSTRUCTION SITE OF GLASSHOUSE (LEFT). DELTABEAM®– STEEL COLUMN CONNECTION (RIGHT).

ÖBB CORPORATE HEADQUARTERS IN VIENNA, AUSTRIA

Project data:
88 meters
23 floors
Building type – Commercial
Developer – ÖBB, Wien
Construction Company - ARGE Habau – ÖSTU-Stettin
Structural Designer – Thomas Lorenz ZT, Graz
Architect – Zechner & Zechner ZT, Wien
Precaster – MABA Fertigteilindustrie, Micheldorf
More info – Peikko Austria GmbH

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Reinforced concrete slabs have been used in ÖBB Headquarters, supported by high-strength precast concrete columns and shear wall cores. Generally, in-situ flat slabs are characterized by the absence of the beams. Whatever loads are exerted onto the slab are transferred directly to the columns, so the columns tend to punch upwards through the slab. To avoid drop panels over column positions in the slab, and to accommodate high shear stresses, Peikko's PSB® Punching Reinforcement was applied in combination with CUBO Column Caps. The thickness of the slab was kept at a relatively low level with the help of PSB® and CUBO. Part of the concrete columns were produced in a precast element factory and delivered with the CUBOs installed. This solution was chosen due to high quality demands defined under Execution Class 3. Peikko also delivered special Fastening Plates to connect inclined precast concrete columns to the slabs.

FIGURE 18 PSB® PUNCHING REINFORCEMENT AND CUBO COLUMN CAP (LEFT). PRECAST CONCRETE COLUMNS WITH SPECIAL FASTENING PLATES (RIGHT).

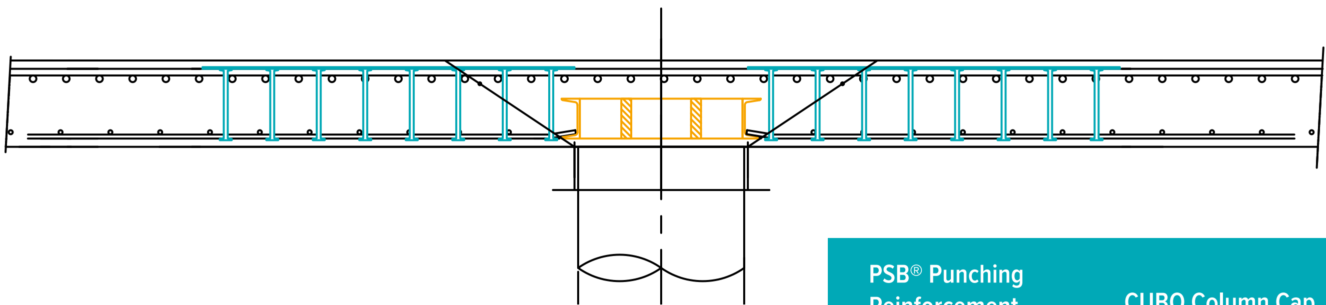


FIGURE 19 FLAT SLAB CROSS-SECTION THROUGH THE COLUMN AT ÖBB HEADQUARTERS.

PSB® Punching Reinforcement

CUBO Column Cap

LIGHTHOUSE IN AARHUS, DENMARK

Project data:
142 meters
43 floors
Building type – Residential
Construction Company – Per Aarsleff A/S
Structural Designer – Rambøll A/S
Architect – 3XN A/S
More info – Peikko Danmark ApS

PSB® Punching Reinforcement

Post-tensioned flat slabs are used for almost every floor of the Lighthouse Tower in Aarhus, Denmark. Post-tensioning helped to achieve the formation of 200 mm thin slabs with up to 8.2m long spans devoid of any column-free spaces. The flat slabs are supported by the central core and the blade columns on the perimeter of the building. In addition, the outrigger action, where the slab is rotationally fixed to the columns and the core, was employed to increase the stiffness of the building against wind loads and vibrations. These requirements made the column-slab connection design very critical, and the high loads on the connections required the use of punching reinforcement for all floors. Peikko's PSB® Punching Reinforcement was selected because the ETA (European Technical Assessment) allows for a higher upper limit of punching capacity than the one provided in the generic Eurocode. Lighthouse Tower is scheduled to be completed in 2022.

FIGURE 20 VISUALIZATION OF LIGHTHOUSE TOWER, ©RUNE KILDEN [4]

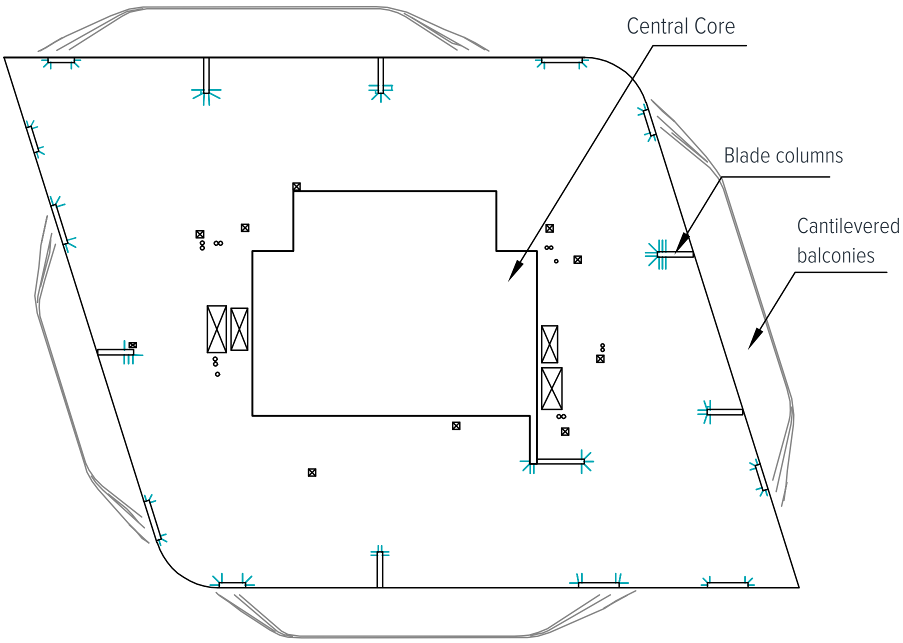


FIGURE 21 STRUCTURAL LAYOUT OF A TYPICAL FLOOR AT LIGHTHOUSE, ©RAMBOLL.

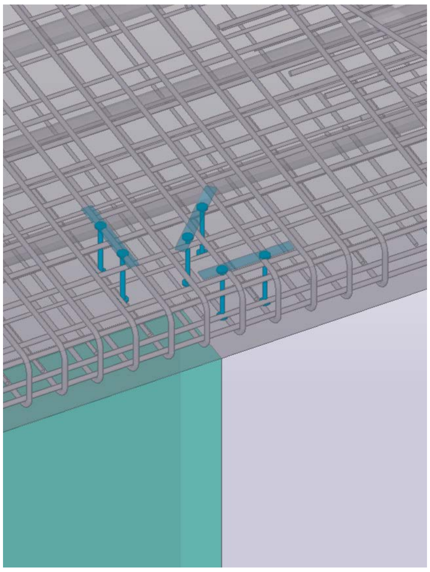


FIGURE 22 PUNCHING SHEAR DESIGN OF A SLAB WITH PSB® PUNCHING REINFORCEMENT AT BLADE COLUMN ENDS, ©RAMBOLL

4.3 ENABLING CLIMBING FORMWORK FOR SHEAR WALL CORES

TAUNUS TURM IN FRANKFURT, GERMANY

Project data:
170 meters
40 floors
Building type – Commercial
Developer – Tischman Speyer, Commerz Real AG
Construction Company – Ed. Züblin AG
Architect – Gruber + Kleine-Kraneburg
More info – Peikko Deutschland GmbH

FIGURE 23 TAUNUS TURM

PCs® Corbels

PC® Beam Shoes

Taunus Turm was designed with closely spaced precast concrete columns along with cast-in-situ shear wall core in the center. The space between the core and perimeter was bridged by prefabricated concrete beams with filigree planks grouted with in-situ concrete. These composite floors act as diaphragms, resisting horizontal forces and transferring them from columns on the perimeter to the central core, which then takes the forces to the ground.

FIGURE 24 STRUCTURAL LAYOUT OF A TYPICAL FLOOR AT TAUNUSTURM, ©ED. ZÜBLIN AG (LEFT). BEAM-TO-WALL CONNECTION WITH PCS® HIDDEN CORBEL (RIGHT).

Cast-in-situ reinforced concrete shear walls and cores are widely spread in Tall Buildings. In-situ concrete technology is favored by engineers due to the structural continuity it provides to the elements. On the other hand, nowadays we can see a clear increase in use of precast concrete technology in Tall Buildings. What makes precast a worthy choice now? Main advantages are its high speed of construction, reduced shoring requirements and an easier quality assurance process to implement. A major challenge in the TaunusTurm was the limited space available on the building site, thus the storage capacity in the upper floors of this tall building was very limited. Prefabricated concrete columns, beams and slabs were selected for the project to eliminate the need for space consuming formwork. To simplify construction, Peikko's PCs® Corbels were implemented to support precast concrete beams while having slipform construction technique for the core. Peikko's PCs® Corbels allowed for the erection of straight mold walls, and at the same time it allowed for the support of beams without having projecting concrete corbels out of the shear walls.

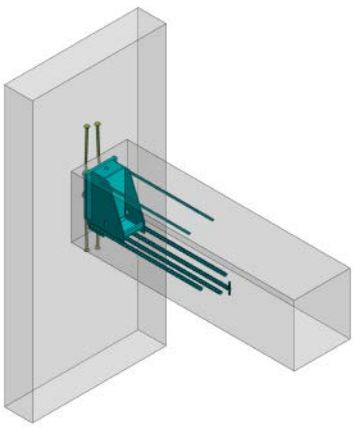


FIGURE 25 ASSEMBLY OF PCS® CORBEL COLUMN PARTS ONTO WALL MOLDS

PCs® Corbels were cast in the shear walls, while matching PC® Beam Shoes were embedded in the precast concrete beams' ends. The corbel plates supporting the beams were bolted after the formwork was removed, thus accelerating and simplifying the formwork turnaround time.

FIGURE 26 ERECTION OF THE BEAM ON PCS® CORBEL PLATE (LEFT). BOLTED PCS® CORBEL PLATE (RIGHT).

PCs® Corbels

MODIX® Rebar Couplers

NORDBRO IN NORREBRO DISTRICT, IN COPENHAGEN, DENMARK

Project data:
96 meters
29 floors
Building type – Residential
Construction Company – KPC & Per Aarsleff A/S
Structural Designer – ÅF Buildings Denmark
Architect – Arkitema
Precaster – MT Højgaard
More info – Peikko Danmark ApS

Same as in the previous project, the contractor was committed to an efficient erection of elements and a rapid progress of the in-situ concrete core. The in-situ concrete core was constructed using climbing formwork. To avoid protruding corbels in the core, which would get in the way of the shape of the climbing formwork, the hidden PCs® Corbel solution was used to support both concrete and steel beams. This resulted in an efficient propulsion of the climbing formwork. In addition to the PCs® Corbels, MODIX® Rebar Couplers were used to handle the horizontal loads between the core and the top concrete of the hollow core slabs.

FIGURE 27 SIDE VIEW OF CONSTRUCTION SITE AT NORDBRO (LEFT). PCS® CORBEL COLUMN PART INSIDE REINFORCEMENT CAGE (RIGHT).

ROCHE TURM BAU 2 IN BASEL, SWITZERLAND

Project data:
205 meters
50 floors
Building type – Commercial
Developer – F. Hoffmann-La Roche AG
Construction Company – ARGE Marti Roche Bau 2
(Marti AG Basel and Marti AG Bauunternehmung Zürich)
Structural Designer – wh-p Ingenieure
Architect – Herzog & de Meuron
More info – Peikko Deutschland GmbH

PCs® Corbels

PC® Beam Shoes

EINDAO / CC BY-SA [5]

The building footprint starts with 32 m x 59 m in floor area, and ends up with 32 m x 16 m area for the upper floor. Similarly to Roche Turm Bau 1 (Tower 1), the floor area of Bau 2 (Tower 2) decreases as the building gets taller. This results in having pre-stressed cantilevered slabs up to 3,6 meters with large openings in the stairway zone. The main stability structure consists of two reinforced concrete cores, fixed in the three-level basement structure.

In this building, to simplify the installation, Peikko provided PCs® Corbels used in staircase walls and PC® Beam Shoes used in precast concrete landing plates. Standard PCs® Corbels were used at first levels, and modified corbels were required at all other levels. Having precast staircases and post-installed corbels proves to be the right solution to accelerate construction time in comparison to the concept used in Tower 1.

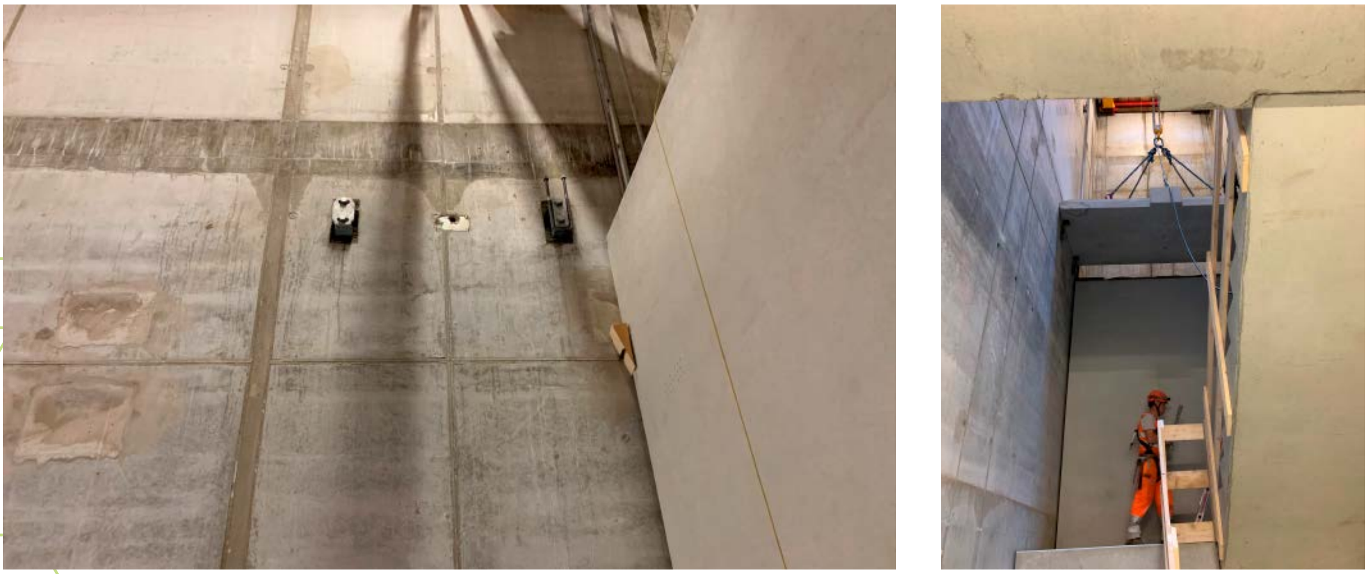


FIGURE 28 PCS® CORBELS CASTED IN THE STAIRCASE WALL (LEFT). ERECTION OF A LANDING PLATE ON THE PCS® CORBELS (RIGHT).

JEWEL TOWERS ON THE GOLD COAST OF AUSTRALIA

Project data:
47, 41 and 34 floors
Building type – Residential
Developer – Yuhu Group
Construction Company – Multiplex
Structural Designer – Arcadis
Architect – DBI Design
More info – Peikko Australia Pty Ltd

ADJUSTA Joint reinforcement

FIGURE 29 AERIAL VIEW AT CONSTRUCTION SITE OF JEWEL TOWERS, ©MULTIPLEX.

The Jewel consists of three towers.The highest, central tower has 47 floors – that's 170 meters tall. The other two are of 41 and 34 floors respectively. The towers' development includes three levels of basement parking.

The lateral system of each building consists of primary reinforced concrete shear wall core with additional shear walls. To maintain the load-path and redistribute gravity and lateral loads from the discontinued columns and walls of the residential part to the basement level, the transfer slab was introduced. This two meter thick slab is a reinforced concrete slab which carries the load of all the floors situated above it and transfers it to the ground through columns.

ADJUSTA Joint Reinforcement was installed in the slab-to-core connections via climbing formwork to enable continuity of reinforcement between the concrete members. The majority of the ADJUSTA connections on the project were 16mm-diameter threaded anchors at 200mm spaced increments between the connections. The deep transfer slabs on 3rd Level carried ADJUSTA 25mm connections at 100mm spaced increments (and in some instances 3 rows) around the core's perimeter. You can see the typical slab-to-core connection with ADJUSTA Joint Reinforcement used on this project in Figure 30. Initially, the ferrule anchors, inserted into the Rebate Former Boards, are cast into the walls. When the concrete has cured, the Rebate Former Board is removed for the second stage installation of the threaded rebars into the anchors. These rebars overlap with the main reinforcement of the in-situ poured concrete slab.

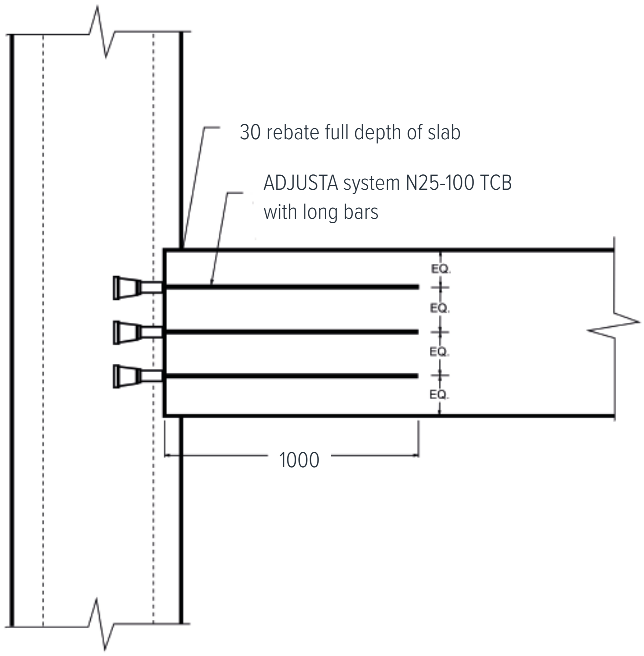


FIGURE 30 CLOSEUP OF ADJUSTA CONNECTIONS FOR THE TRANSFER SLAB INSTALLATION, ©MULTIPLEX (LEFT). SECTION DRAWING OF WALL-TO-TRANSFER SLAB CONNECTION (RIGHT).

4.4 SIMPLIFYING CONNECTIONS BETWEEN STRUCTURAL COMPONENTS

OMNITURM IN FRANKFURT, GERMANY

Project data:
190 meters
46 floors
Building type – Office and residential building
Developer – Tishman Speyer
Construction Company – Adolf Lupp GmbH & Co. KG
Structural Designer – Bollinger + Grohmann, PfeiferundPartner Part GmbB
Architect – Bjarke Ingels Group (BIG)
Precaster – Adolf Lupp GmbH
More info – Peikko Deutschland GmbH

HPKM® Column Shoe

COPRA® Anchoring Coupler

A central feature of the architectural concept is the "hip swing", an alternating cantilevering of the 15th to 22nd floors (residential floors) by up to five meters in different directions. At that level, the building forms a spiral by shifting the stories along its vertical axis. Above the 22nd floor, the tower returns to rationally optimized floor areas and thus completes its rotation to realign with the structure outline beneath. This architectural feature presented several challenges to the structural designers. Inclined columns were giving extreme horizontal forces, which were transferred with the help of steel ties through the slabs into the stiffening core.

Additionally, the first three base levels, designed as public space, are also offset along the vertical axis, which meant that the geometry of the support sections had to be optimized in order to minimize inclinations and deflections of the columns.

The office floors from level 3 to level 15 and level 23 to the roof of the building have the same regular floor plates. For these typical floors, the diaphragm consists of main and secondary precast concrete beams with cast-in-situ slab on top.

The main beams run between the exterior columns and support secondary beams between the stiffening core and the perimeter frame. With this configuration, the secondary beams create an eccentric load and tend to twist main beams laterally. To avoid torsional moments in the beams, Peikko's HPKM® Column Shoes and COPRA® Anchoring Couplers were specified on all levels above the second floor.

This solution transfers tension forces through the joints of a cast-in-situ structure in a quasi-monolithic behavior, and allows for fast assembly of the precast construction. In addition, the column shoes meet all requirements, including R120 fire resistance for the load-bearing structure.

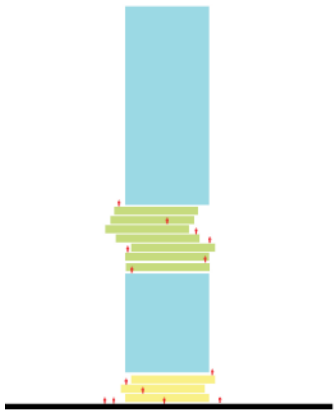


FIGURE 31 ARCHITECTURAL CONCEPT OF OMNITURM, ©BIG

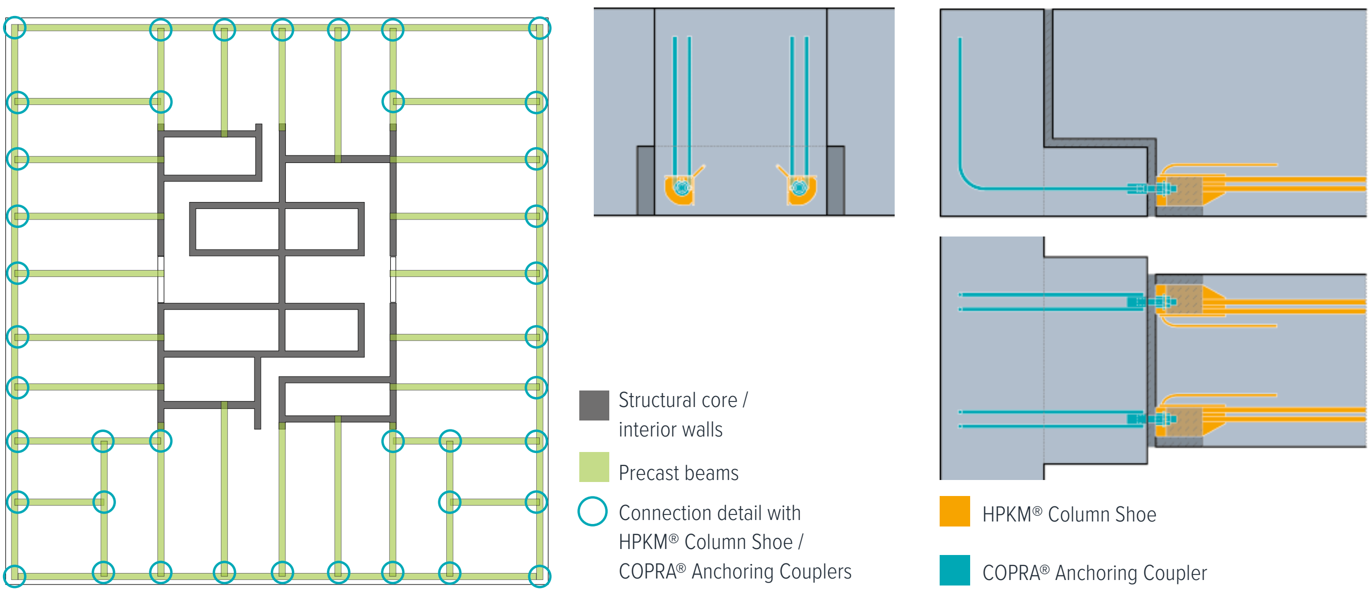


FIGURE 32 SCHEMATIC STRUCTURAL LAYOUT OF L03-L13 IN OMNITURM (LEFT). ILLUSTRATION OF MOMENT RESISTING CONNECTION BETWEEN MAIN AND SECONDARY BEAMS DESIGNED FOR OMNITURM (RIGHT).

COPENHAGEN TOWERS IN DENMARK

Project data:
85 meters
22 floors
Building type – Commercial
Developer – Sjælsø
Construction Company – Per Aarsleff A/S
Structural Designer – ÅF Buildings Denmark
Architect – Foster + Partners
Precaster – CRH Concrete A/S.
More info – Peikko Danmark ApS

HPKM® Column Shoe

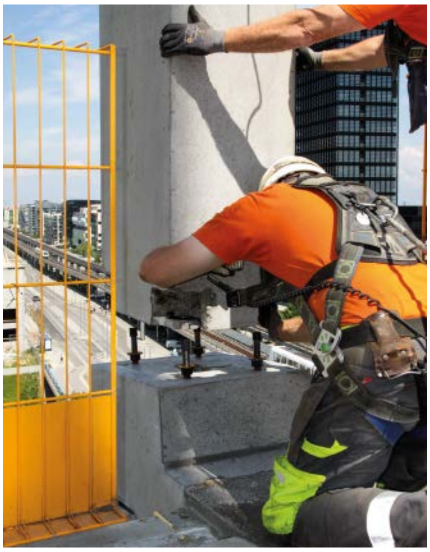
COLIFT Mounting System

© H.L.NE MOGENSEN DE MONL.ON

The building complex consists of 2 towers and 3 smaller wings, which are situated around a central atrium space. The 22-story high North Tower is special for its curved facade columns. Since crane time was decisive when building this tower, it was decided to use two-story precast concrete columns in the facade. The two-story façade columns, as well as all other precast concrete columns (140 in total), were done with Peikko's HPKM® Bolted Column Connections. This solution helped to reduce the number of operational cranes from three to two during one of the construction phases of the building. The beauty of a bolted, mechanical connection is that columns can be installed with a small crew on site, and no temporary bracing is required. As soon as the nuts are tightened, the connection is moment-resistant, and the crane can move on to the next column. Furthermore, Peikko's Bolted Connections are full-scale tested and ETA approved, which ensures that the stiffness of Peikko's column connection is at least as rigid as a continuously reinforced cast-in-situ column connection.

Often the construction process becomes very costly due to non-operational delays of cranes caused by strong winds. These are the common conditions in Nordic countries during autumn and winter periods. With the use of COLIFT Mounting System, the erection of the precast concrete columns is less wind-sensitive. COLIFT Mounting System allows the column to be released remotely from the ground, without lifting up a man to release the mounting device at the top of the column. Peikko's Bolted Connections and COLIFT Mounting System ensure safe erection operations with wind speeds up to 15 m/s (54 km/h), whereas other traditional columns are allowable to erect up to a limit of 10 m/s (36 km/h). The combination of these two solutions allows for an extended construction period in unfavorable weather conditions.

FIGURE 33 SIDE VIEW OF CONSTRUCTION SITE AT COPENHAGEN TOWERS.



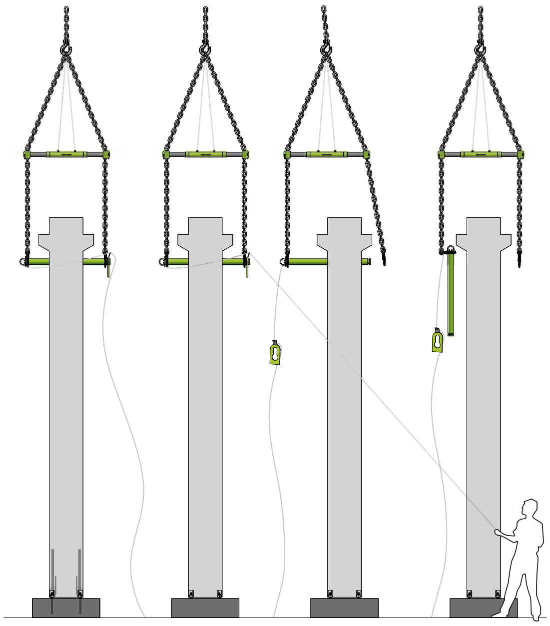


FIGURE 34 ERECTION OF THE PRECAST CONCRETE COLUMN ON ANCHOR BOLTS' PRE-LEVELED NUTS AND WASHERS (LEFT). RELEASING PROCESS OF COLIFT MOUNTING SYSTEM FROM PRECAST COLUMN (RIGHT).

4.5 DESIGN FLEXIBILITY THROUGH PEIKKO SOLUTIONS

ICON IN VÄXJÖ, SWEDEN

Project data:
67 meters
20 floors
37 000m^2
Building type – Commercial and Residential
Developer – APP Equity AB
Construction Company – Prefabsystem Entreprenad Syd
Structural Designer – Peikko Lietuva UAB
Architect – Semrén & Månsson
More info – Peikko Lietuva UAB
DELTABEAM® Composite Beams – 5800m
Composite columns and steel structures – 700t

FIGURE 35 A THREE-STOREY CROWN STRUCTURE OF ICON.

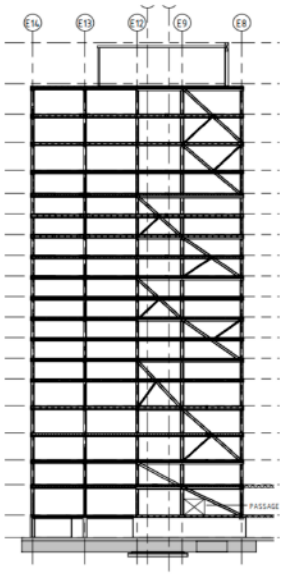
The 20-story-tall ICON, with its boldly cantilevered form, is a new landmark in the Växjö skyline. The full frame stability design of the ICON was done by Peikko. Global stability of the building was achieved with braced DELTABEAM® Frame, a steel and concrete composite structure consisting of composite columns and DELTABEAM® Composite Beams. The composite frame was paired with hollow core slabs and precast elevator shafts.

With DELTABEAM® Frame, you can maximize space utilization, making room for more people within the same available space. Besides slim floors that allow for higher floor-to-ceiling heights (or more floors for a given building height), slender composite columns take up very little space, which translates into more floor area to sell or rent.

In the ICON, the structural system of the DELTABEAM® Frame is based on nominally pinned joints between beams and columns, while the sway stiffness of the frame is arranged by the diagonal braces. In braced structure like this, most of the beams and columns were designed under vertical load only, assuming the braced bays carry all the lateral loads. Lift shaft due to very low axial load was not used as a lateral load-resisting part.

A unique feature of the building is a three-story crown structure that forms the top three floors of the building and extends up to 14 meters beyond the main building's footprint. The primary cantilever structure consists of a system of 4 structural steel bolted cantilever trusses located above the residential levels with floors made from cellular beams and composite deck.

FIGURE 36 SIDE VIEW OF CONSTRUCTION SITE AT ICON.



DELTABEAM®
Composite Beam

DELTABEAM®
Frame

4.6 OTHER SOLUTIONS FOR TALL BUILDINGS

DC TOWERS COMPLEX IN VIENNA, AUSTRIA
DC TOWER 1

Project data:
220 meters
60 floors
Building type – Commercial and Residential
Developer – WED AG
Construction Company – Max Bögl
Structural Designer – Bollinger-Grohmann-Schneider
Architect – Dominique Perrault
More info – Peikko Austria GmbH

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The Donau City complex consists of Donau City Tower 1, Donau City Tower 2 and Donau City 3. The tallest 220 m high DC Tower 1 was completed in 2013. The second tower will be about 168 meters high. But before that, the much smaller DC Tower 3 will be built, in which a student dormitory will be located. Two towers, DC 1 and DC 2, should represent an uneven, in-the-middle-broken monolith, and at the same time form the gateway to the Donau City.

A reinforced concrete structure was used for DC Tower 1. Flat slabs span between the core and the columns. Lateral stiffness of the building was achieved by two elements – in-situ core with walls of up to 1m thickness and 2m thick outrigger slabs above the MEP plant floors which activate the columns. The mass pendulum system was used to fulfill serviceability requirements regarding maximum acceleration in the upper residential floors.

The connection between the individual reinforced concrete members is established with Peikko's MODIX® Rebar Coupling Systems. The reinforcing couplers of DC Tower 1 were implemented using over 45000 MODIX® Rebar Coupler connections. The columns were connected with SM36 and outrigger slabs to the core mainly with SM40 couplers. SM20, SM26 and SM30 were employed to connect the typical slabs to the core.

More than 40,000 double-headed studs of Peikko's PSB® Punching Shear Reinforcement System enable construction of flat slabs, preventing punching shear failure. In addition to MODIX® Rebar Couplers and PSB® Punching Reinforcement, Peikko provided about 12 tons of special steel components that form part of the supporting structure and the connections between structural components. Custom-made steel components have always been part of Peikko's portfolio. DC Towers is an excellent example which shows the complexity level of the structures that Peikko can manufacture to meet all quality requirements.

PSB® Punching Shear Reinforcement

MODIX® Rebar Couplers

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