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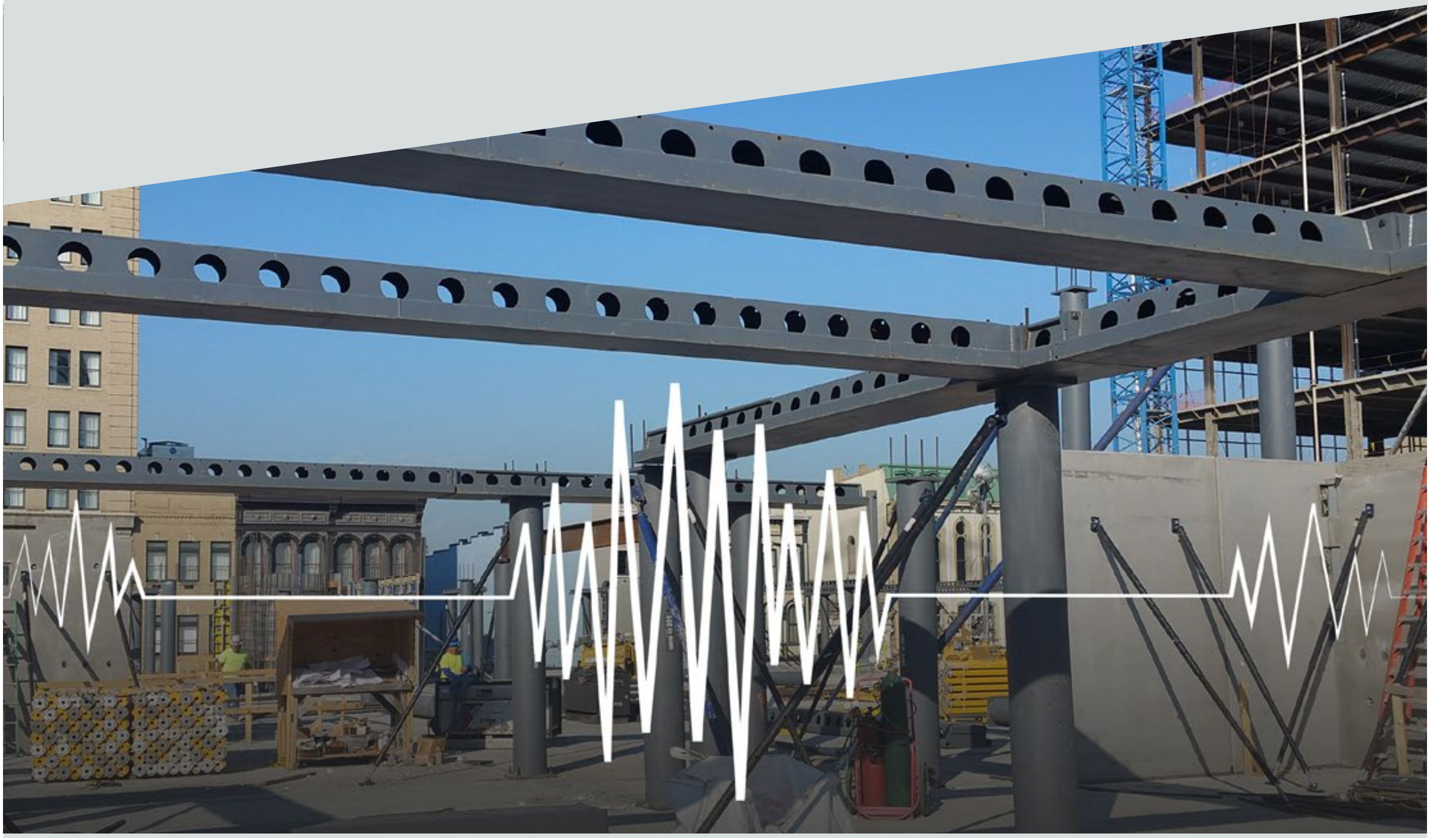
WHITE PAPER



DELTABEAM® USE IN SEISMIC AREAS – DESIGN RECOMMENDATIONS AND CASE STUDIES

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The modern way of building larger and taller challenges the designers, especially in the seismic areas. In order to continuously support customers’ needs, Peikko has been developing safer, faster and more efficient ways to build for years, and now we are largely aiming to find solutions for seismic design requirements.

INTRODUCTION

Earthquakes are sudden and intense events that are caused by ruptures in the Earth’s crust as a result of the constant movement of tectonic plates against each other, which makes seismicity a global risk (Figure 1). Fortunately, earthquakes generally have a low probability of occurrence, which means that they might or might not occur in a 50-year lifetime of a structure. However, nobody can predict exact time, location and magnitude of an earthquake. Therefore, structures should normally be resistant to earthquakes so that they do not collapse, and human lives are protected.

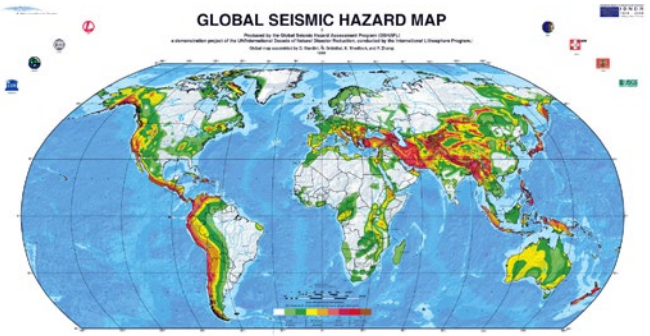
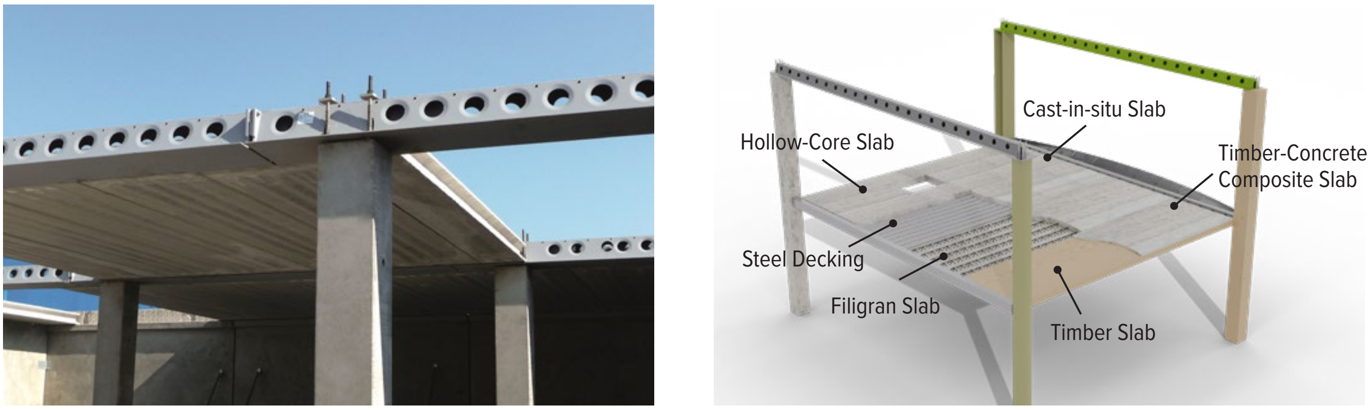


FIGURE 1 SEISMIC HAZARD MAP [5]

Being crucial to life safety, seismic design requirements are a priority in the building construction. All the stakeholders, such as the designer, the architect, the engineer and the suppliers, must be aware of them and work together so that seismic issues are considered and matched at every stage of the design process. Since the aim of Peikko is to provide innovative solutions for a faster, safer and more effective way to design and build, different research projects have been carried out in the recent years and still continue in order to provide up-to-date information on how to use Peikko products in safe and reliable way when it comes to the seismic parameters.

Among these projects, lots of resources and efforts are now put on DELTABEAM® Composite Beam, as beams play one of the main roles in carrying the design loads within the structure. DELTABEAM® is a slim floor composite beam that is integrated into the depth of the slab (Figure 2a). Its composite action between steel and concrete allows for structures with large open spaces and enables slender and light structural solutions that provide savings in terms of volume and costs. DELTABEAM® can be also used with several technologies, such as precast and cast-in-situ concrete, steel or composite structures, and suits different slab types as well (Figure 2b). And when designed properly and according to the standards, DELTABEAM® structures are safe to be used for seismic applications too, keeping the architectural and design benefit of slim floor structures at the same time.



a) b)

FIGURE 2 (A) DELTABEAM® SLIM FLOOR STRUCTURES (B) DELTABEAM® WITH DIFFERENT SLAB TYPES

EARTHQUAKES AND STRUCTURES

Earthquakes are dynamic phenomena, meaning that during an earthquake, the ground is rapidly accelerated back and forth, but the mass of a building does not instantly follow these movements. This causes strong vibrations and internal inertia forces in the structure, which result in large displacements and deformations (Figure 3). Reinforced concrete and steel constructions of civil engineering can generally sustain such deformations thanks to ductility. It is the property of certain materials to fail only after considerable distortion has occurred, which allows for energy dissipation. At structural level, ductility can be seen as a reserve capacity of the members to resist seismic load, which might even exceed their design resistance.

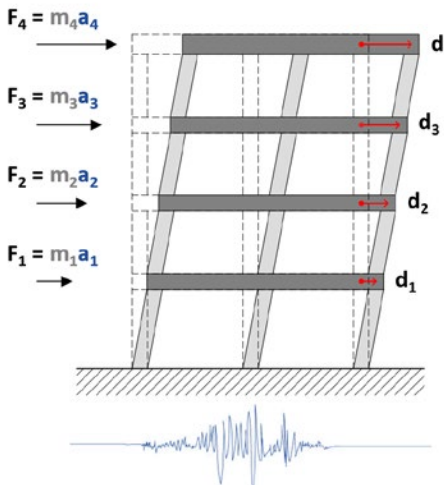


FIGURE 3 MODELLING OF SEISMIC FORCES AND THEIR EFFECT ON A STRUCTURE

However, the intrinsic ductility of materials is still not sufficient. As an example, steel rebars are generally ductile, but when embedded in concrete, they can give this material considerable ductility only if proper reinforcement detailing is provided. Moreover, a satisfactory global seismic performance relies both on the properties of the elements themselves, such strength and stiffness, and on the cyclic behavior of the connections between them. This means that a ductile beam, for instance, can develop its deformation capacity only when beam-column joints are able to transfer the loads and allow for the expected displacements (Figure 4).

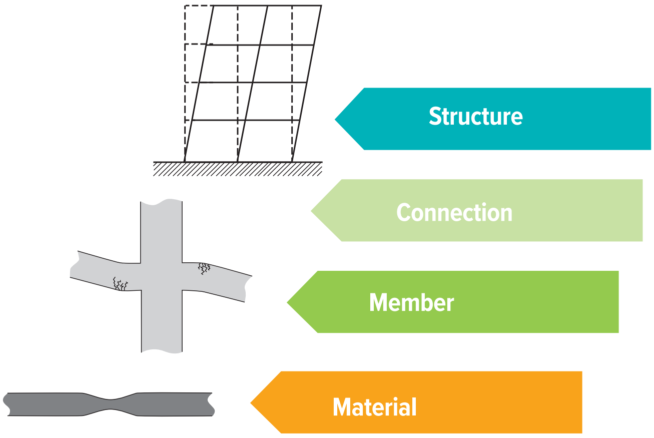


FIGURE 4 DUCTILITY LEVELS: FROM THE MATERIAL TO THE STRUCTURE

The whole building configuration is what determines the way the seismic forces are distributed and resisted by the structure. A regular, symmetric and redundant structure will show a better performance than a discontinuous and irregular one. In fact, evenly distributed structural elements allow for a more favorable load sharing, while continuity of the members, both in plan and in elevation, guarantees direct transmission of the seismic forces (Figure 5). Moreover, a structure that follows the basic seismic design principles of simplicity, uniformity and regularity implies less uncertainties in the modelling, analysis, dimensioning and detailing, thus leading to a more reliable prediction of the seismic behavior.

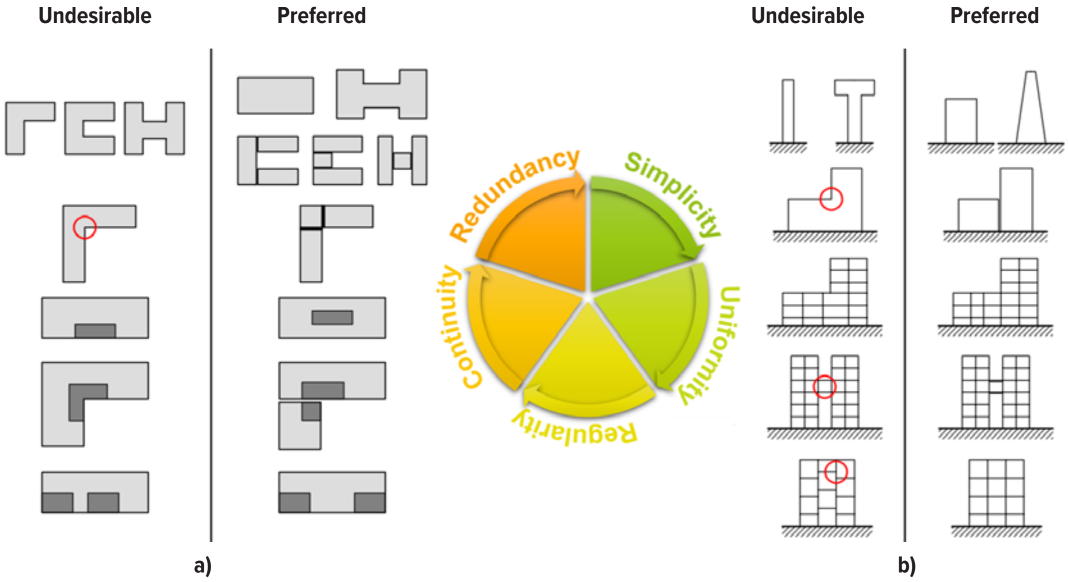


FIGURE 5 BASIC PRINCIPLES OF SEISMIC DESIGN: (A) PLAN AND (B) VERTICAL CONFIGURATIONS IN BUILDINGS (ADAPTED FROM [7])

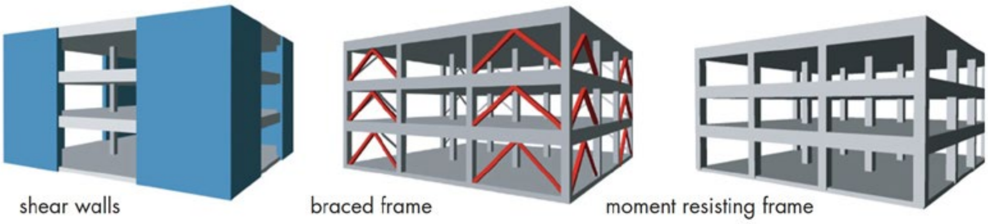


FIGURE 6 ALTERNATIVES OF SEISMIC RESISTING SYSTEMS [1]

The definition of the seismic resisting system is therefore crucial. Basically, seismic designers can choose among three alternative types of lateral force-resisting systems: shear walls, braced frames and moment resisting frames (Figure 6). Shear walls are designed to receive lateral forces from the floors and transmit them to the ground. To be effective, shear walls must run from the top of the building to the foundation with no offsets and a minimum of openings. In braced frames, the bracings act in the same way as the shear walls. However, they generally provide less resistance, but also increased deformation capacity. Sometimes, they are preferred because they also provide more architectural design freedom than shear walls. A moment resistant frame is the engineering term for a frame structure in which the lateral forces are resisted primarily by bending in the beams and columns mobilized by strong joints between columns and beams. Such performance is achieved by applying more demanding structural design requirements to both elements and connections.

In any case, whichever the seismic resisting system is, there should be clear understanding of the role of each structural member, whether it is supposed to take the seismic loads or not. In fact, once the lateral force-resisting system is identified, there can be also other parts of the structure, which are designed based on standard code design conditions to carry gravity loads only (Figure 7). Combined, even though separate, seismic resisting structures are nowadays increasingly common as the search for economy of structure leads to the concentration of seismic resistance into fewer elements. Nevertheless, the gravity load-resisting system should be well connected to such elements so that the global stability of the building is ensured.

This implies the following challenges. First, joints and connections become even more crucial to transferring the actions between the parts up to the seismic resisting elements. The load path should be clear so that each connection can be designed for the expected load condition. Beside resistances, deformation capacity and compatibility with in-plane / out of plane deformations must be checked. For example, gravity-only columns need to accommodate horizontal seismic deflections without damage. Although these columns are not designed to resist seismic forces, they do experience the same horizontal movements as the primary force resisting system. Moreover, allowance for large deformations that might occur at element interfaces has to be guaranteed.

Once the above aspects are taken into account, then the use of separate seismic and gravity resisting systems brings several benefits, which are even maximized when combined with DELTABEAM® slim floor structures.

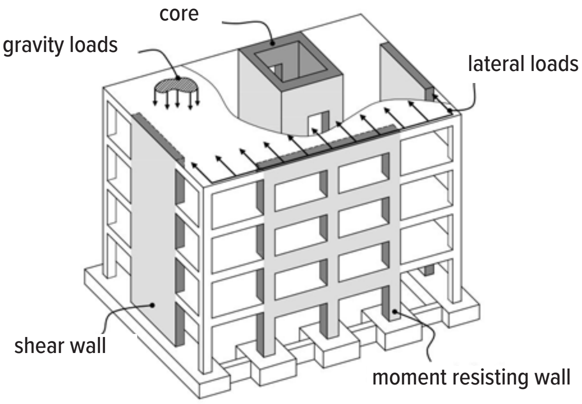


FIGURE 7 EXAMPLE OF SEPARATE SEISMIC AND GRAVITY RESISTING STRUCTURE

SEISMIC DESIGN OPTIONS FOR DELTABEAM®

While using DELTABEAM® in seismic applications, one can benefit from the floor height reduction and minimize the building's total height in two ways (Figure 8). First, reduction of the mass of the floors brings the reduction of the inertia forces that will be applied to the structure by the earthquake. In fact, floors are generally where the mass of a building is mostly concentrated. Limited slab depth results then in less mass and less inertia. Secondly, the reduced building height with the same number of stories helps to control the lateral displacement or drift. In practice, when subjected to horizontal seismic load, each story undergoes displacements that are proportional to the floor height. Therefore, limited height implies limited deformation demand for both structural and non-structural elements, thus preventing or limiting possible damage.

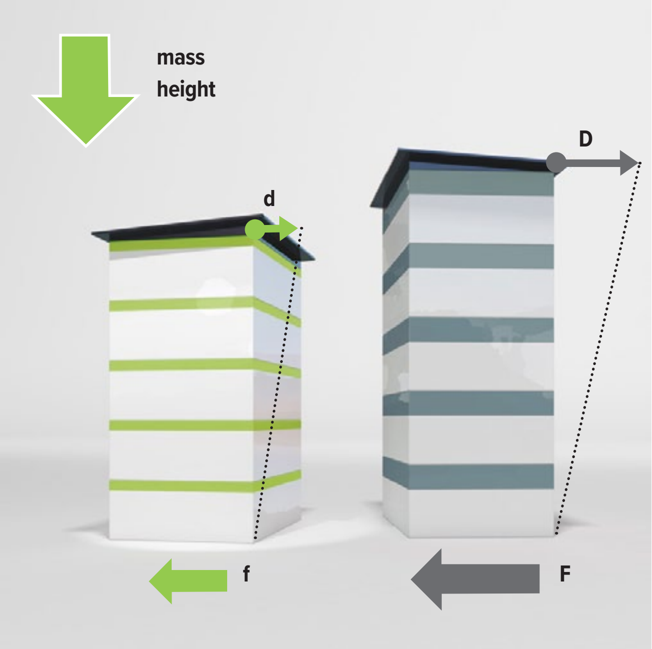
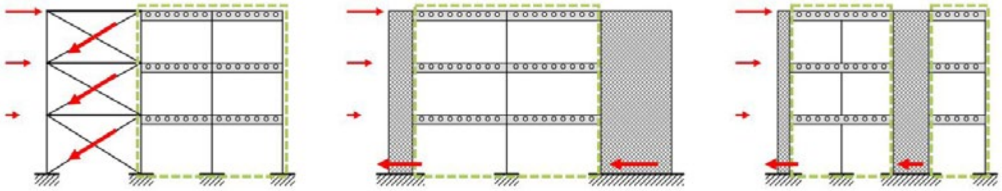


FIGURE 8 BENEFITS OF DELTABEAM® SLIM FLOOR STRUCTURES IN SEISMIC APPLICATIONS



a) b) c)

FIGURE 9 – DESIGN OPTIONS FOR DELTABEAM® COMBINED WITH (A) STEEL BRACINGS AND (B) CONCRETE WALLS OR (C) WITH PINNED COLUMNS

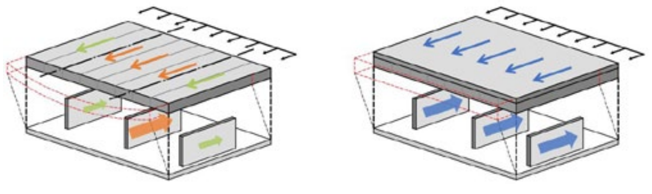
DELTABEAM® frames can be conveniently designed to carry vertical gravity loads only, when combined with seismic resisting systems in precast or cast-in-situ concrete, steel and composite structures (Figure 9). In such combined structures, DELTABEAM® acts as a secondary component for seismic resistance, while the lateral stability is provided by, for example, bracings, walls or cores. When separating seismic from gravity structure, more floor configuration options are available as the regular grid no longer needs to be superimposed on the whole floor plan. At the same time, DELTABEAM® wide spans leave architectural freedom, too.

Moreover, DELTABEAM® enables fast and efficient construction phase by using simple connections that have less design issues than the rigid ones. In fact, entirely seismic resisting structures usually imply detailing and construction complexities and costs. On the contrary, design and costs issues can be reduced when DELTABEAM® simple connections are used at certain locations. Sometimes, columns of gravity resisting system can also be detailed with pinned joints top and bottom in each story so as to not attract seismic forces to themselves, which allows the use of DELTABEAM® continuous lines in the most efficient way.

DELTABEAM® AND FLOOR DIAPHRAGMS

The term diaphragm is generally used to indicate the role that floors, or roof elements, play in the global seismic performance of the building. More precisely, floors are the horizontal-resistance members that are to transfer the forces between vertical-resistance members by combining them into a single lateral load resisting system. Sometimes, horizontal bracing systems independent of the roof or floor structure serve as a diaphragm as well.

Diaphragms may act either in a flexible or rigid manner, depending partly on the floor's material, size and geometry (Figure 10). Solid concrete slabs or slabs with concrete topping with adequate thickness are usually considered rigid diaphragms, which is generally the case. In turn, wood or steel decking without concrete is flexible. The flexibility of the diaphragm affects the way the forces are distributed. If the diaphragm is rigid, walls or columns share the loads in proportion to their stiffness. On the contrary, loads are shared according to the tributary mass of each vertical element in flexible diaphragms, if the mass is evenly distributed.



flexible diaphragm rigid diaphragm

FIGURE 10 FLEXIBLE AND RIGID FLOOR DIAPHRAGM BEHAVIOR

Rigid floor diaphragms are generally used and preferred as they mitigate and balance back asymmetrical stiffness distribution. In fact, floor diaphragms contribute to avoid torsional effects and concentration of stresses, which are created by lack of balance between the location of the resisting elements and floor layout (Figure 11). Floors and roofs have to be penetrated by staircases, elevator and duct shafts, skylights, and atria (Figure 12a). The size and location of these penetrations are critical to the effectiveness of the diaphragm. The reason for this is clear when the diaphragm is visualized as a beam, where the openings cut in the tension flange of a beam will seriously weaken its load carrying capacity. In a lateral load system, this might be even more critical, as the hole would be in the region of both tension and compression, since the loading alternates rapidly in direction.

In order to provide in-plane resistance and to ensure load transfer despite such structural discontinuities, floors are generally provided with collectors, also called drag struts or ties, which are diaphragm framing members that "collect" or "drag" diaphragm shear forces from laterally unsupported areas to vertical resisting elements (Figure 12b). Perimeter reinforcement and cast in situ strips can be placed to tie together the floor elements. Sometimes, the beams themselves can act as collectors, by having both adequate axial capacity and connection to vertical elements.

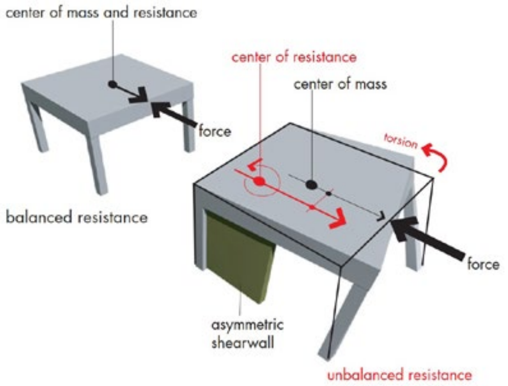
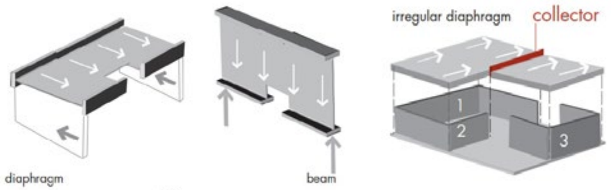


FIGURE 11 TORSIONAL EFFECT OF UNSYMMETRIC FLOOR AND STRUCTURAL ELEMENTS DISTRIBUTION [1]



a) b)

FIGURE 12 FLOOR VS. DEEP BEAM ANALOGY AND COLLECTORS (ADAPTED FROM [1])

For the above reasons, the diaphragm action should be always accounted for and the role of the beams has to be checked, even when DELTABEAM® is supposed to carry gravity loads only. Figure 13 shows different types of floors in combination with DELTABEAM®. DELTABEAM® cross section A is integrated in a cast-in-situ concrete slab. Such sections can be used in seismic areas without any problems when properly reinforced in both directions, since they have enough stiffness provided by their thickness. Cross-sections B and C depict a combination of DELTABEAM®, floor elements and cast-in-situ concrete top layers. Floor elements might be typically hollow-core units, but timber slab elements or others can be used as well. As such, those floor elements would be flexible since they are not continuous in plan, but they can be made as rigid if a cast-in-place topping, with minimum thickness, typically 70 mm at least, and bi-directional reinforcement are provided, according to Eurocode provisions. In addition, adequate tying between the floor units and the beam itself should be provided.

The case D shows a floor without topping, which can have the advantage of lower weight and depth. In this case, a satisfactory shear transfer can be provided by mechanical connectors or special profiles along the edges of the units. Special features of joints with waved shear keys have been tested and showed effectiveness (Figure 14). However, floors without topping should not be used in areas of high seismicity and must be applied with caution in areas of moderate seismicity. The case of basements should be mentioned separately. In fact, underground structures are assumed to move along with the surrounding ground, and therefore they are not subjected to horizontal accelerations. However, vertical movements due to earthquakes occur also in basements. Thus, a minimum topping to avoid cracks along the joints and additional ties are recommended, as shown as an example in Figure 15, where DELTABEAM® sits on PCs® Corbel and rebars are placed in the concrete topping.

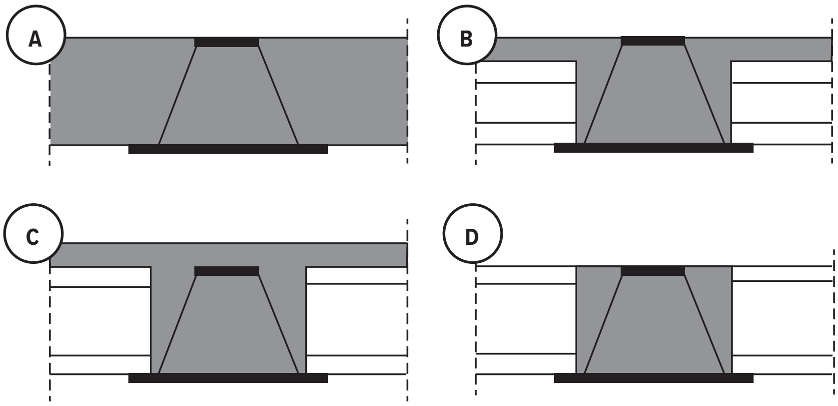


FIGURE 13 DELTABEAM® AND DIFFERENT FLOOR TYPES

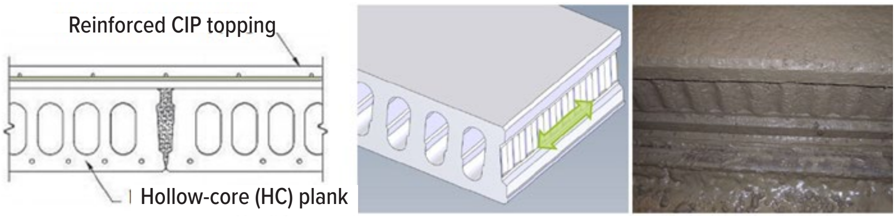


FIGURE 14 FLOOR DIAPHRAGM AND HOLLOW CORE UNITS: REINFORCED TOPPING AND WAVED SHEAR KEYS [4]

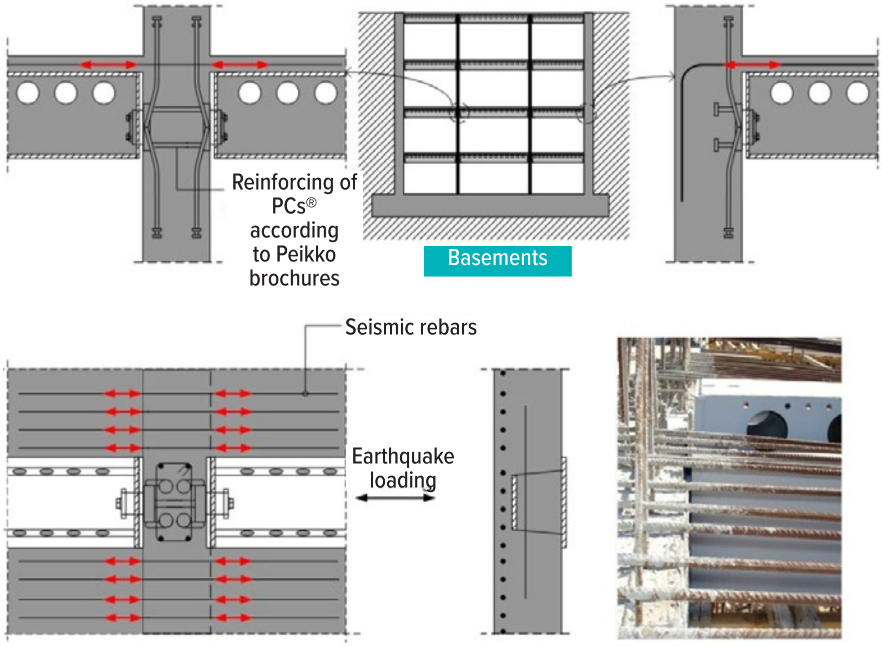


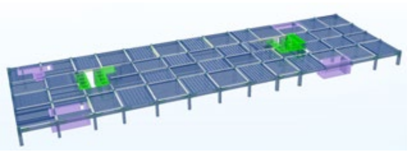
FIGURE 15 EXAMPLE OF TYING REINFORCEMENT IN BASEMENT STRUCTURES

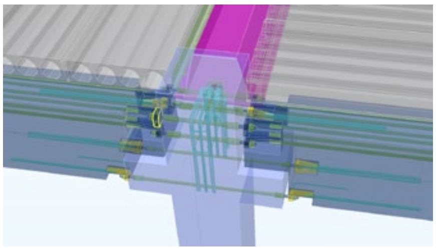
NEWPORT LINK PROJECT, PASAY, PHILIPPINES

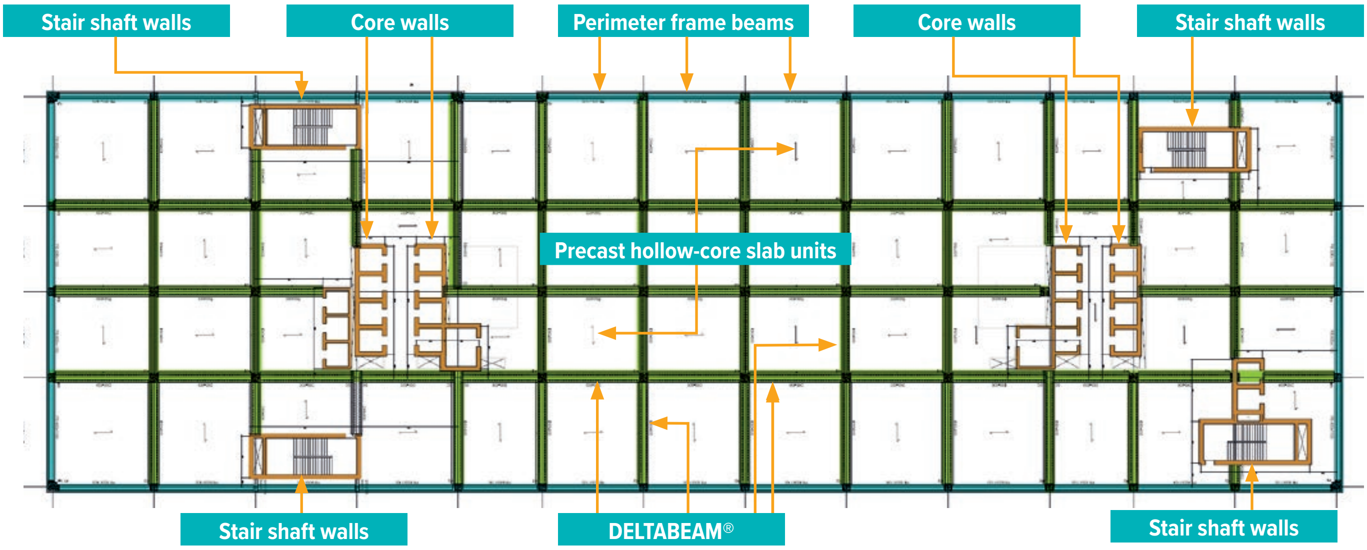
Year of Construction	Planning phase
Building Type	Multi-use
Structural Designer	STATICA
Lateral Resisting System	Cast-in-situ concrete walls and perimetral precast moment resisting frame
Seismicity	Very high
More info	Peikko APAC

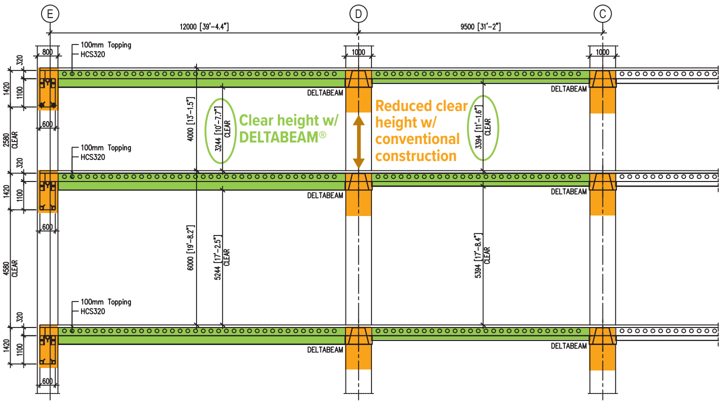
Newport Link Project is located in the city of Pasay, Philippines, which is a highly seismic area of the so called Ring of Fire that surrounds the Pacific Ocean. The project is a multi-use complex building, with the potential to be used as a casino. The proposed structure is a very efficient dual system, which combines cast-in-situ concrete walls, precast moment resisting frame and DELTABEAM®. Needs for the project are speed of construction and large open spaces. COPRA® Anchoring Couplers and HPKM® Column Shoes are used in rigid beam-column joints along the perimeter, while DELTABEAM® is simply supported on interior columns by using PCs® Corbel.

Having interior columns that support gravity forces, while perimeter frames resist all seismic forces, has its advantages. As a matter of fact, the perimeter frames provide the best torsion resisting layout due to maximizing the lever-arm between them. Since seismic moment frame beams are relatively deep, their peripheral layout enables inter-story heights to be kept to a minimum thanks to DELTABEAM® slim floor structure. Moreover, by confining the large seismic resisting columns to the perimeter they are less disruptive to interior planning and potentially function as cladding elements, reducing façade costs.









LUXEMBOURG, QUÉBEC CITY, QUÉBEC, CANADA

Year of Construction	2012-2021
Building Type	Residential
Construction Company	Logisbourg
Structural Designer	EQIP Solutions
Lateral Resisting System	Cast-in-situ/precast concrete shear walls and steel bracings
Seismicity	Moderate high
More info	Peikko Canada

Luxembourg project consists of four buildings with 5 residential levels over 2 parking levels. DELTABEAM® is used with composite columns and the floor is made with hollow core units. Each building uses a different technique for the lateral resisting system.

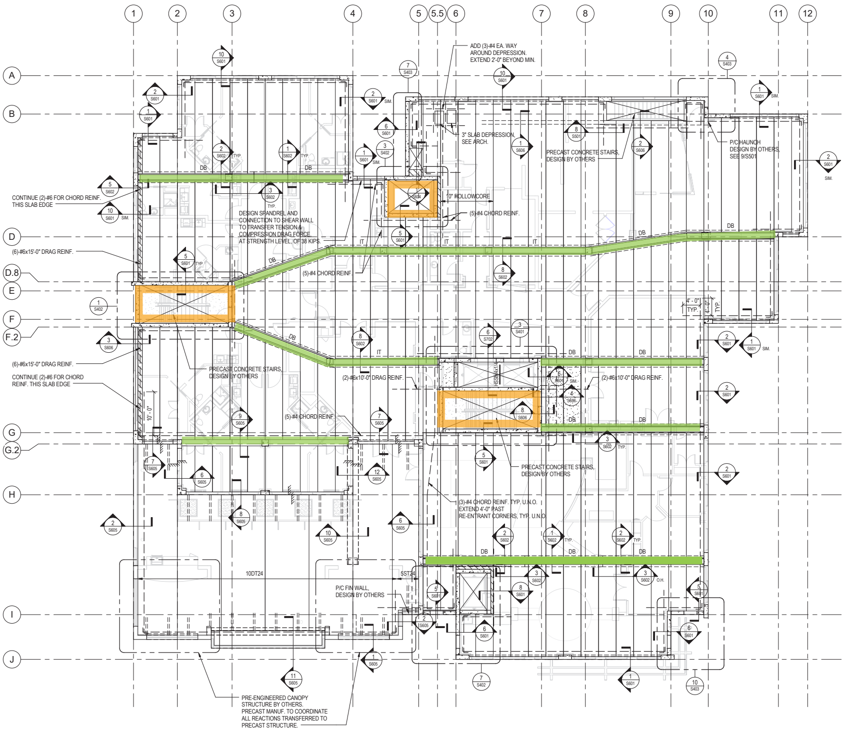
At first, the structure was designed to have cast-in-situ shear walls, which resulted in being too time consuming on site. Precast shaft large elements were then used, which allowed for faster erection of the walls. Some of them were connected by large weld plates, while others used SUMO® Wall Shoes and PPM® Anchor Bolts, which speeded up the construction even more by avoiding site welding. As the precast shaft elements were quite massive and heavy, in the last phase of the project steel bracings were selected for the lateral resisting system. Main advantage of this system is the reduced weight compared to concrete and the fact that it can be preassembled on the ground, thus shortening the installation phase. The long story of this project shows how DELTABEAM® can suit different structures and quickly adapt to changes in design and building phases.

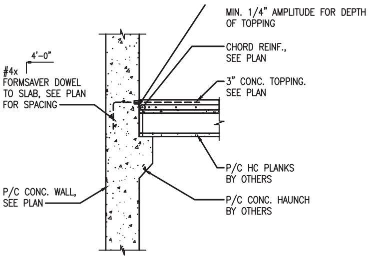
THE PLAZA AT WAIKIKI, HONOLULU, HAWAII, USA

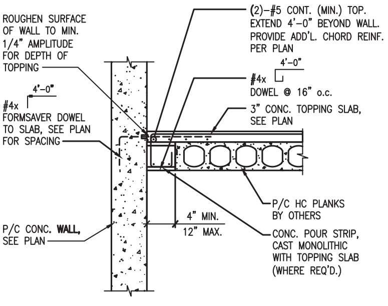
Year of Construction	2014
Building Type	Commercial and residential
Construction Company	Sound Health Hawaii Llc.
Structural Designer	Baldrige & Associates Inc.
Lateral Resisting System	Cast-in-situ concrete shear walls
Seismicity	High
More info	Peikko USA Inc.

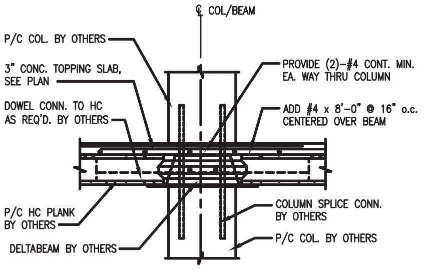
The Hawaii islands are a good example of seismicity local distribution. Spanning only on an approximately 200 km distance, going from West to East, the seismicity increases from low to very high. The Plaza at Waikiki relies on the concrete shear walls of the stair shafts for the lateral resistance. The system is defined as an intermediate precast wall system, meaning that the walls are designed to have the same strength and stiffness as ordinary cast-in-situ concrete walls. Columns are precast and the slab is made with hollow core units. DELTABEAM® is designed to be continuous over the columns with pin-pin condition and bearing on concrete corbels at stair shaft location.

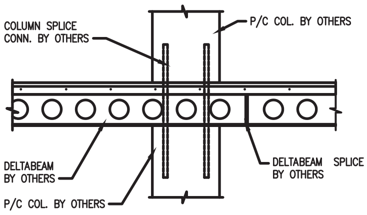
The close-up view of the floor during the construction shows the bidirectional reinforcement in the concrete top layer, which, according to local regulations, is mandatory to achieve a rigid floor diaphragm. Threaded inserts ensure then the transfer of the in-plan forces to the vertical structural elements. Studs are welded on DELTABEAM® top plate to get the composite action and benefit from the concrete topping as part of DELTABEAM® capacity.

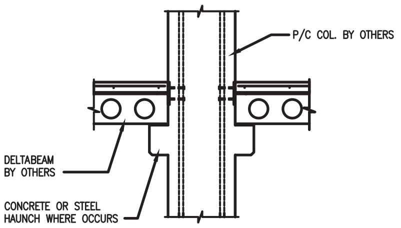






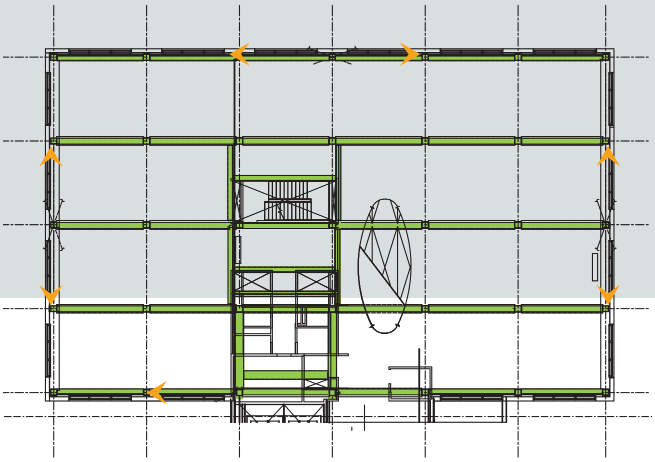






NIR CENTER, PORTLAND, OREGON, USA

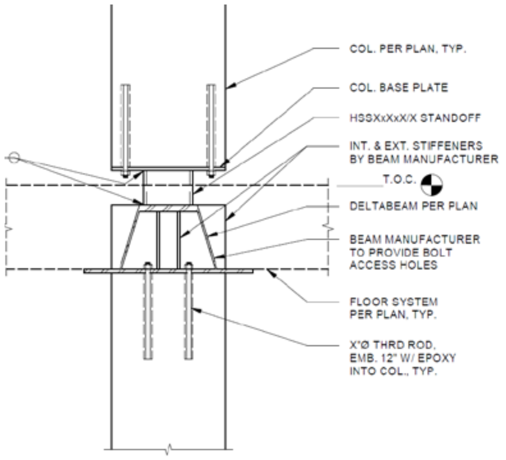
Year of Construction	Under construction
Building Type	Laboratories
Construction Company	Holmes Structures
Structural Designer	Hennebery Eddy Architects Inc.
Lateral Resisting System	Buckling resistant bracings
Seismicity	Very high
More info	Peikko USA Inc.

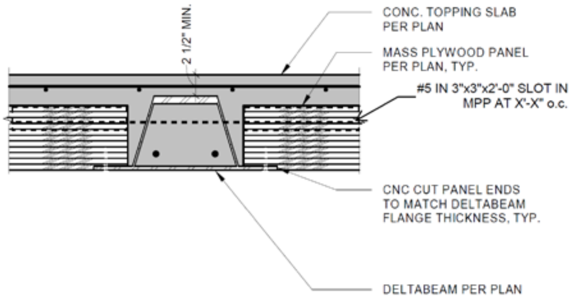


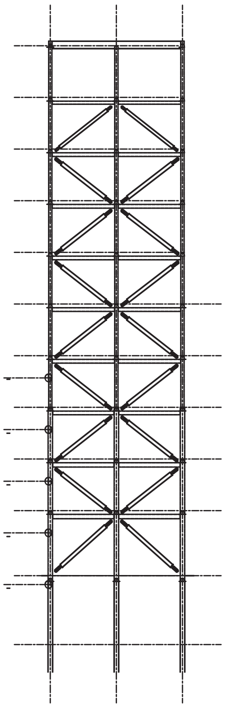
In the north-west of the United States, Oregon is a very high seismic area, as all the countries facing the Pacific Ocean and located close to the boundary of the Pacific tectonic plate. A steel buckling restrained braced (BRB) frame is designed as a lateral load resisting system in the NIR Center. BRBs consist of a steel plate encased in a concrete filled hollow steel section (HSS) tube. Such system provides lateral resistance in both directions as buckling of compressed steel members will not occur thanks to the infilled concrete. Bracings are placed symmetrically in both directions of the building to achieve regularity in plan and even distribution of strength and stiffness.

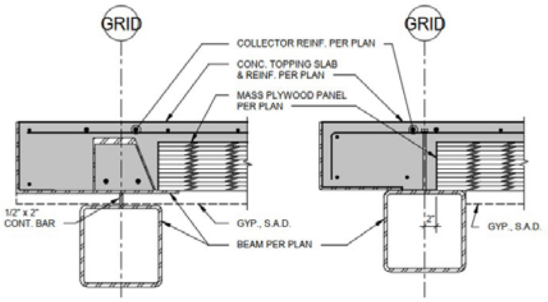
The rest of the structure is made with wood elements, i.e. glulam columns and massive plywood panel (MPP) slab, while DELTABEAM® is continuous sitting on top of the columns. The use of wood slabs and columns makes the structure extremely light compared to other construction materials, which is beneficial in the reduction of the inertia forces under seismic loading. Moreover, the combination of DELTABEAM® and composite concrete-wood slab is attractive for the customer as it allows for slim floor solution, which is generally difficult to achieve with traditional massive wood structures.

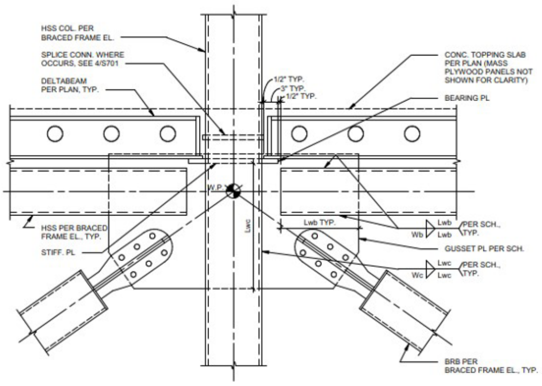
The reinforced concrete topping provides adequate in-plan stiffness for the diaphragm action to the slab units, which are connected to the beam with rebars and studs. All the axial loads are carried by the HSS under the beam, meaning that DELTABEAM® is strictly designed for gravity.









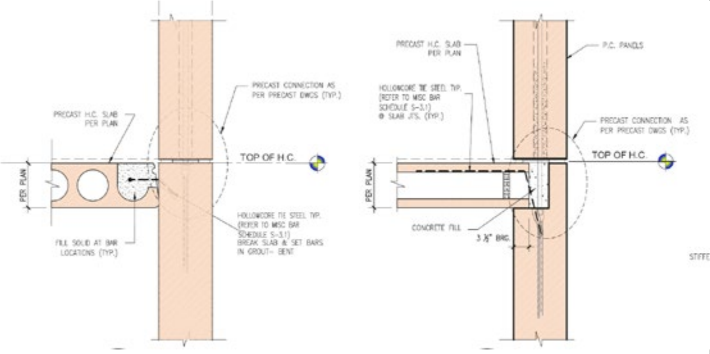


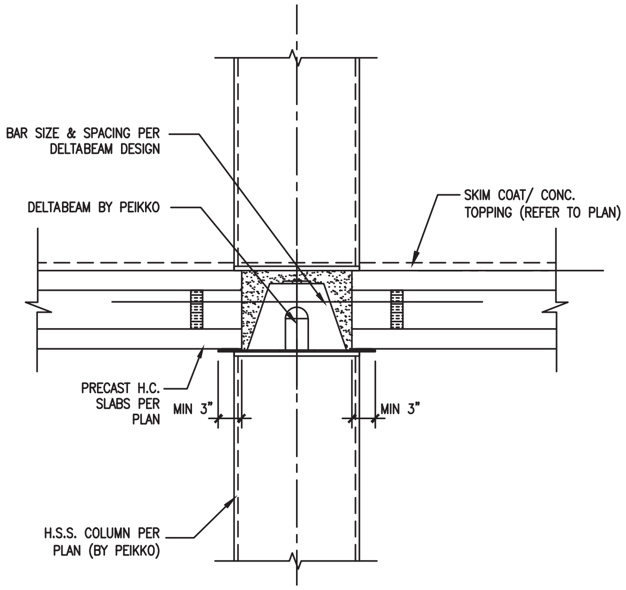
CENTER POINTE, LEXINGTON, KENTUCKY, USA

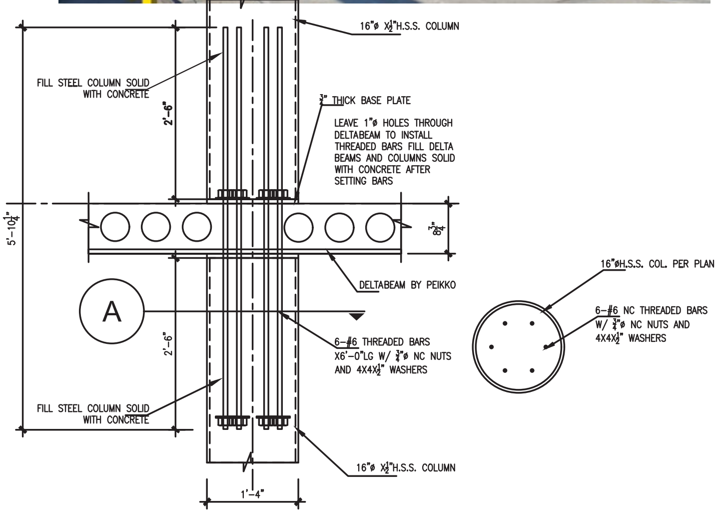
Year of Construction	2018
Building Type	Hotel
Construction Company	The Bristol Group
Structural Designer	Hgs Ltd. Consulting Engineers
Lateral Resisting System	Precast concrete shear walls
Seismicity	Low moderate
More info	Peikko USA Inc.

The Center Point project is composed by two hotel buildings connected with each other via an underground parking. The project is an example of combined structure where precast shear walls are designed for lateral load while DELTABEAM® frames with composite columns are supposed to carry gravity loads only. The clear separation of the structural roles of the two resisting systems enables the use of beam lines, which is generally not allowed in seismic resistant frames, but in turn is structurally convenient as it allows longer spans compared to single spans.

However, vertical reinforcement continuity between column splices should be always guaranteed to ensure the load transfer within the whole structure. For that purpose, holes were cut into DELTABEAM® top and bottom plates to install threaded bars before pouring concrete inside the composite columns, in order to achieve adequate axial resistance. Floors are made with hollow core units that are bearing on top of the walls for gravity and connected by drilled epoxy anchors grouted in the voids for lateral resistance.



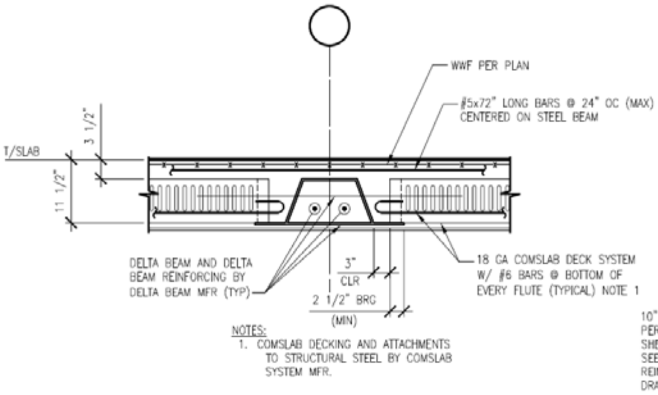


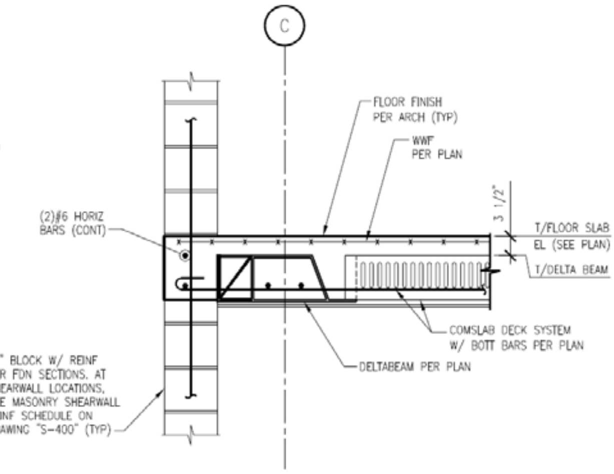


BLACKBURNE CONDOS, PITTSBURGH, PENNSYLVANIA, USA

Year of Construction	2019
Building Type	Residential
Construction Company	Whitney Bailey Cox & Magnani
Structural Designer	JMAC Architects
Lateral Resisting System	Reinforced masonry shear walls
Seismicity	Moderate
More info	Peikko USA Inc.

Blackburne Condos project is a combined structure, where the steel frame is not specifically designed for seismic resistance, which is in turn assigned to reinforced masonry shear walls. Simply supported one-span DELTABEAM® is placed in both orthogonal directions of the frame. The connection with wide flanges columns is achieved by using bolted end plates that are designed as pinned joints.
Reinforced concrete topping with adequate thickness is poured on the steel deck to provide horizontal stiffness to the floor. Moreover, rebars are placed in each flute of the steel sheet to connect DELTABEAM® and the slab, thus achieving horizontal tying.



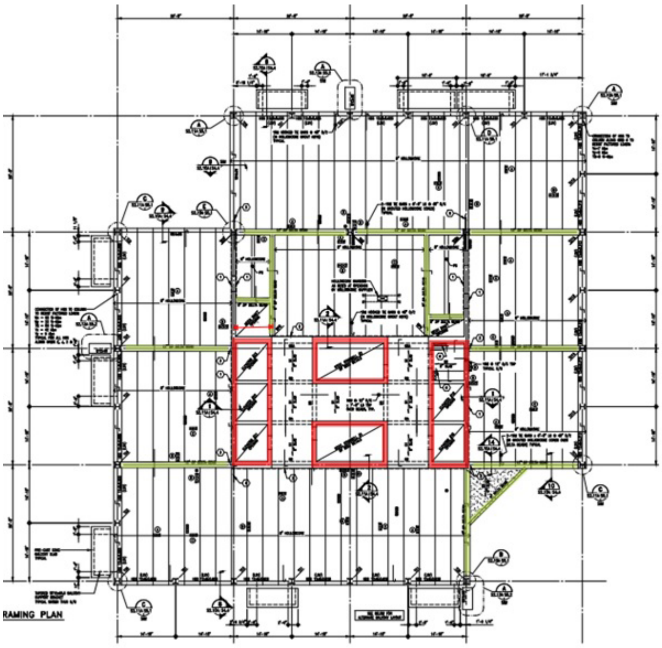


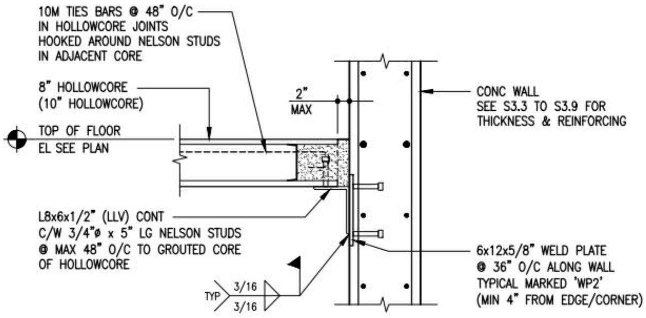
300 MAIN, WINNIPEG, MANITOBA, CANADA

Year of Construction	2018-2021
Building Type	Commercial and residential
Construction Company	Marwest
Structural Designer	Crosier Kilgour & Partners
Lateral Resisting System	Cast-in-situ concrete shear walls
Seismicity	Low
More info	Peikko Canada Inc.

DELTABEAM® was definitely selected for 300 Main building in order to maximize the number of floors in certain height allowance. In fact, the building is now the tallest in the city of Winnipeg, with its 142 meters and 43 stories. The structure benefits of the slim floor concept, which allowed for a lighter construction and resulted in remarkable savings in the construction of the foundations as well.

The project is located in a low seismicity area, which is reflected by light seismic requirements. Nevertheless, cast-in-situ concrete shear walls are designed to carry the horizontal forces that might come from wind or seismic loading. Gravity connection and lateral connection are achieved by one single connection, i.e. weld plates casted into the walls. PCs® Corbels welded onto the wide flanges of the columns are used for the connection between DELTABEAM® and the columns. In-plane horizontal continuity is ensured by steel rebars going through DELTABEAM® and hollow-core slabs. The diaphragm is achieved through the hollow cores alone, as concrete topping is a non-reinforced skim coat.



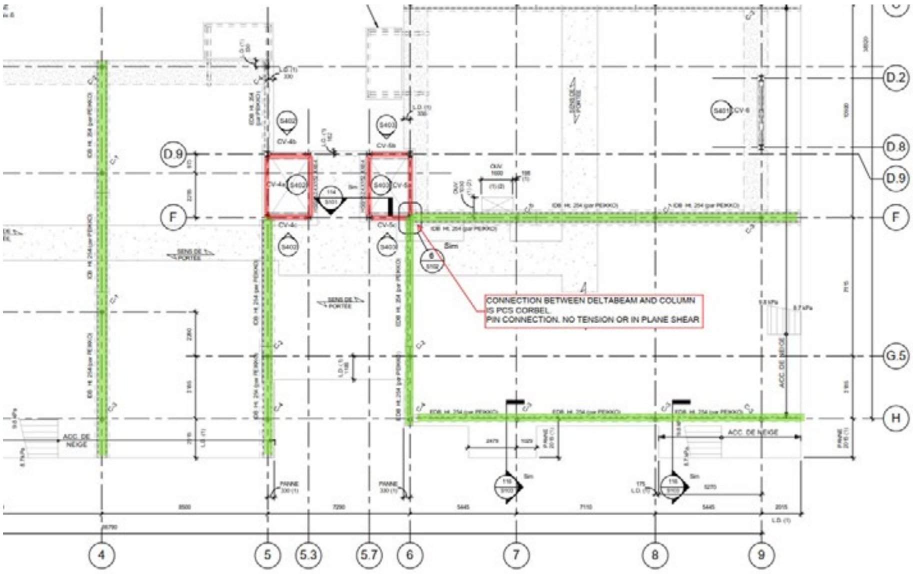


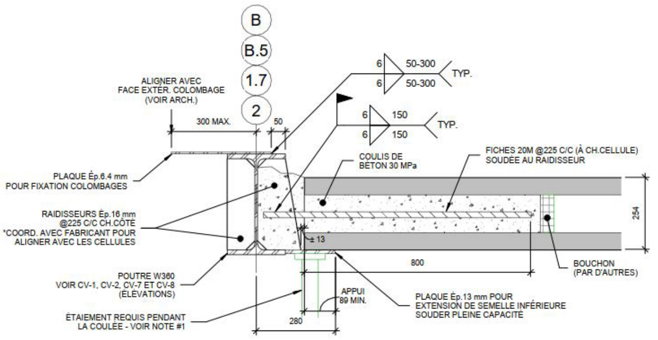
LE PIVOT, QUÉBEC CITY, QUÉBEC, CANADA

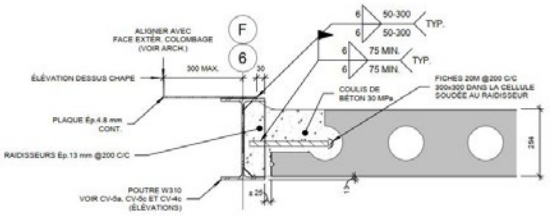
Year of Construction	2019
Building Type	Residential
Construction Company	Hectare Construction
Structural Designer	Équipe Solutions
Lateral Resisting System	Steel bracings
Seismicity	Moderate high
More info	Peikko Canada Inc.

Le Pivot is a 7-story high residential building located in a moderate-high seismic zone in the city of Québec. Steel bracings are designed to carry the lateral loads, while DELTABEAM® continuous lines over composite columns are supposed to take the gravity loads. The slab is made with hollow-core units. The connection between the diaphragm and the lateral resisting system is done through the slab instead of the DELTABEAM®. This is preferable since the in-plane load can be transferred through several meters on the slab rather than on a localized point at beam location.

Steel bracings have regular gussets on the wide flange. Steel rebars welded on the gussets are embedded and grouted into the hollow-core voids in order to connect the bracings to the floor. DELTABEAM® sits on PCs® Corbels welded on the wide flange columns, which means that vertical shear only is transferred at beam-column joint.





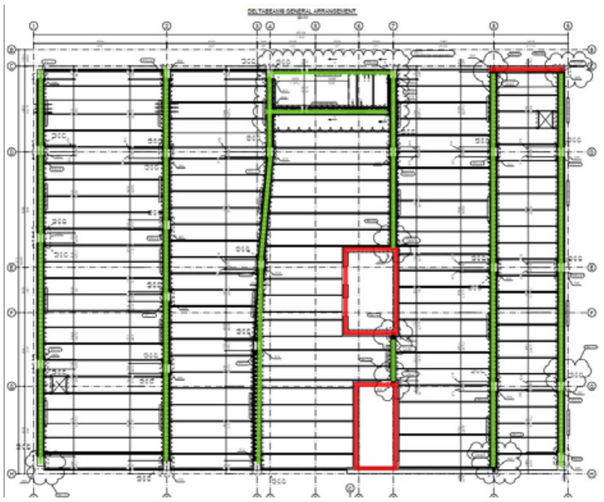


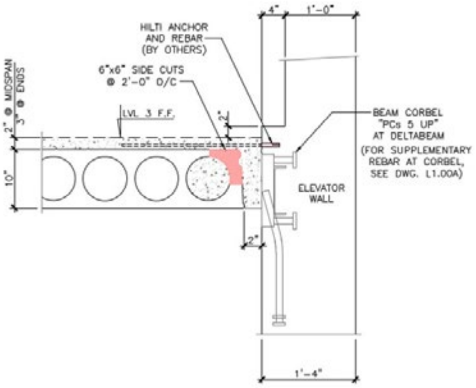
FRANKLIN STORAGE, VANCOUVER, BRITISH COLUMBIA, CANADA

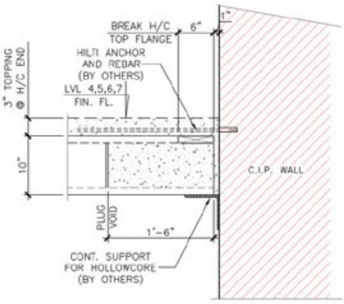
Year of Construction	2020
Building Type	Storage facility
Construction Company	Key Self Storage
Structural Designer	Conforce Precast
Lateral Resisting System	Cast-in-situ concrete shear walls
Seismicity	High
More info	Peikko Canada Inc.

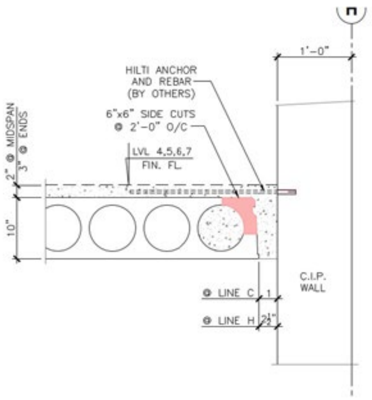
Cast-in-situ concrete shear walls have been designed to give lateral resistance to the 7-level Franklin Storage building. In fact, the building is located on the Western coast of Canada, which is a high seismic area. DELTABEAM® is supported by PCs® Corbels at its ends, whether they are walls or precast column. All precast columns are using HPKM® Column Shoe at their base.

In this project, connections with the cast-in-situ walls rely on different mechanism: steel angles or PCs® Corbels are used for gravity and threaded inserts through the concrete topping provide lateral resistance. In fact, the diaphragm is achieved with a 75 mm thick reinforced concrete layer over the hollow-core units.







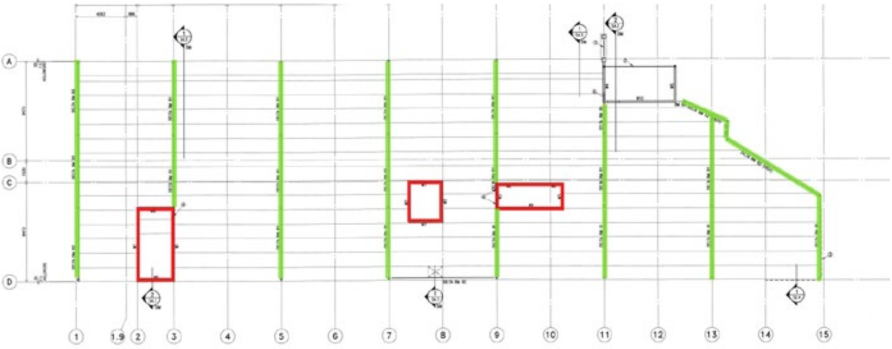


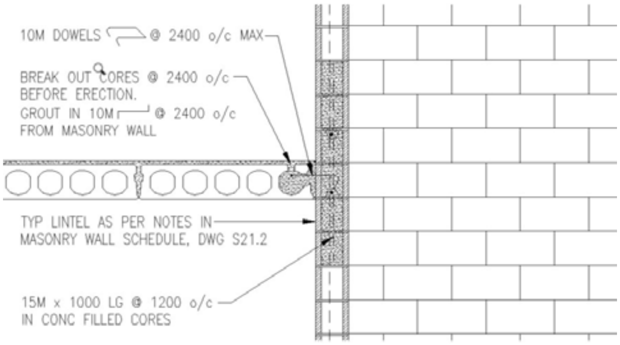
GRAND HOTEL, WINNIPEG, MANITOBA, CANADA

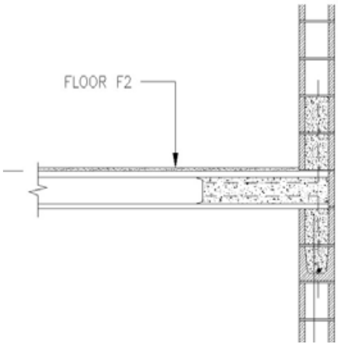
Year of Construction	2011
Building Type	Hotel
Construction Company	Thomas Design Builders
Structural Designer	Crosier Kilgour & Partners
Lateral Resisting System	Concrete-masonry cores
Seismicity	Low
More info	Peikko Canada Inc.

Concrete-masonry units (CMU) are a construction technique where precast concrete blocks filled with fresh concrete and reinforced with steel rebars are used for walls in low-rise buildings. CMU are quite popular in Winnipeg, and they have been used for the three main cores of the Grand Hotel to provide lateral stability to the structure.

DELTABEAM® and hollow steel section (HSS) columns account for the vertical resistance. DELTABEAM® ledge can be shaped so that it wraps the column, where PCs® corbel is welded on. The diaphragm action is achieved by rebars going through the hollow-core units and overlapping to the reinforcement in the CMU elements.





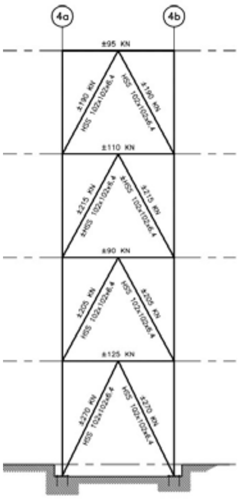


BOLTON STREET APARTMENT, OTTAWA, ONTARIO, CANADA

Year of Construction	2014
Building Type	Residential
Construction Company	Beaudoin Construction
Structural Designer	Cleland Jardine
Lateral Resisting System	Inverted V steel bracings
Seismicity	Moderate high
More info	Peikko Canada Inc.

Bolton Street Apartment is a low rise building in the city of Ottawa, which is a moderate high seismic region. In this case, inverted V steel bracings are used as lateral resisting system, therefore DELTABEAM® results to be integrated into the base brace system. Such system is not very common as usually the bracings are hidden into walls. However, inverted V bracings allow door openings under the brace. Columns are wide flange type, and the floor is made with hollow-core units.

The magnitude of the axial force in the beams is about 100 kN. DELTABEAM® is designed for compression flexure by considering the steel cross-section only. Top and bottom plate are slotted at the ends to accommodate the bracing gussets. At bracing locations, columns have the bracing connection at one side and PCs® Corbel at the other side, the first having high tension capacity and the other limited one. In fact, in this case the diaphragm is achieved through the slab and not through the beam itself.

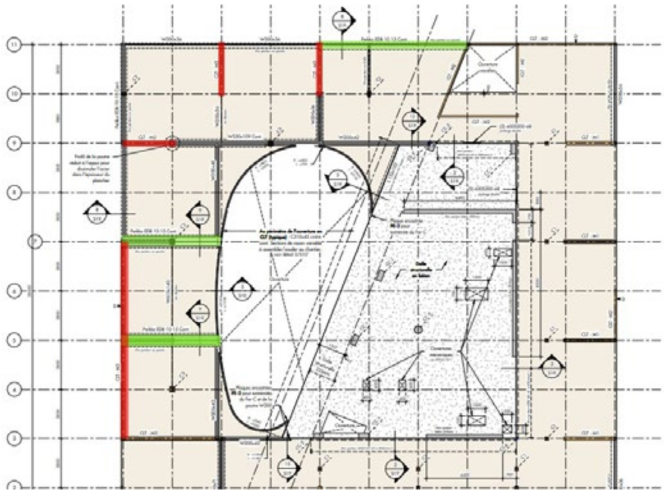


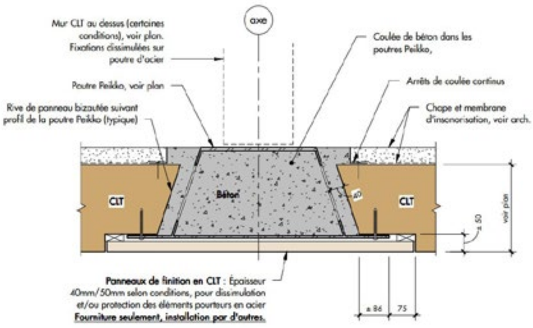
INSTITUT QUANTIQUE, SHAREBROOKE, QUÉBEC, CANADA

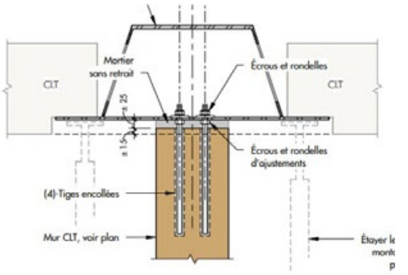
Year of Construction	2020
Building Type	Institutional
Construction Company	Construction Gératek
Structural Designer	Latéral
Lateral Resisting System	Cross-laminated timber walls
Seismicity	Moderate high
More info	Peikko Canada Inc.

Institut Quantique in Québec is a quantum-mechanic pavilion in the city of Sharebrooke. The project is interesting as it combines several different structural techniques, such as cross-laminated timber (CLT) slabs and walls, Glulam columns, concrete walls and steel beams, in addition to DELTABEAM®. The bolted connection between DELTABEAM® and walls or columns is made with threaded rods glued into the timber element

It is then clear that combining different materials, structural elements and also lateral resisting systems is absolutely possible, even in elevation. For example, in this project there is also a transition from concrete shear walls at the ground floor to CLT walls in the upper floors.







CONCLUSIONS

Seismic design needs a comprehensive approach that starts with the structural concept, continues with the definition of the lateral load resisting system, and ends with the detailing of the structural members and their connections, which should in turn comply with the initial assumptions. The integration of structures for seismic and/or gravity loads is best begun early in the design process so that the role of each element in the overall stability of the building can be well defined and then checked.

The structural diversity or hierarchy resulting from the separation of these structural systems requires a more conscious design, but at the same time it offers benefits from both architectural and structural points of view. In fact, appealing DELTABEAM® slim floor solutions and easy-to-design DELTABEAM® simple connections can be used when walls, cores or bracings already provide required resistance to lateral forces.

Different combinations of structural resisting systems can be applied, as there is no pre-defined arrangement that works in all design cases. The applicability of a specific structural typology depends on many factors, such as the seismicity of the site, the project conditions and the current design Codes. Nevertheless, the above examples of projects show the versatility of DELTABEAM®, and there is even more potential as the investigation for Peikko solutions for seismic applications still continues.

ACKNOWLEDGEMENTS

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