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DISMOUNT AND REUSE
OF PRECAST CONCRETE FRAME

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INTRODUCTION

Currently, a great deal of interest and attention is paid on sustainability and climate neutrality at EU level. This is shown by the actions of European Commission, which has set targets, presented in European Green Deal strategy [1], to be climate neutral by 2050. For supporting those targets, it has published Circular Economy Action plan [2], which describes more concrete actions to take in different key value chains.

While construction and buildings are considered as one of those key value chains, the construction sector is responsible for more than 35% of EU's total waste generation and 5-12% of global GHG emissions [2]. Additionally, according to Eurostat [3], the construction sector used 29% of total non-renewable raw materials in 2018.

The Green Deal strategy [1] and Circular Economy Action plan [2] are giving the guidance not only at European level legislations, but also at national level. The Building and Land use Act (132/1999) in Finland is under review and will take actions, for example, to ensure the low carbon footprint of the buildings. The Finnish Ministry of Environment has published Method for the whole life carbon assessment of the buildings [4], which describes how to calculate both carbon footprint and handprint of the building. The new act is leading the design towards carbon neutral buildings.

New low carbon buildings are not the only answer to reach the climate neutral targets in building industry. One aspect of Circular Economy, defined in ISO 20400 [5], is aimed at keeping products, components and materials at their highest utility and maintaining their value through the whole life span of the building. The buildings can be designed to support the disassembly and the adaptability of their structures, and the potential of existing building stock may also be utilized. This can lead to effective reduction in need of new structures, cutting both GHG emissions and raw material consumption of the construction sector.

Design-for-disassembly is an important design principle, since it enables maintenance, replacement, and reuse of the components after their designated service life. Furthermore, the design for circularity means both selecting the sustainable raw materials and enabling the desired functions of the components and their connections. While a building component can include low carbon raw materials with high recycled content, it can also be replaceable, maintainable, and reusable.

Reuse and disassembly were not considered in design phase of the existing building stock and that makes the reuse of their components rather difficult. Even now, building components are not usually designed to be disassembled, refurbished, or reused. There is a lack of common understanding about the relevant design principles for reused load-bearing structures and most of the current design norms do not support this kind of approach. Additionally, there is no verification system for assessing the fit of old, especially concrete structures, for reuse. However, none of these challenges may really hinder the disassembly and reuse of the precast concrete structures at the level of practice. The reuse of steel structures and their fit for use has been already studied in RFCS-funded project PROGRESS [6]. The study presents different kinds of reuse scenarios and how to evaluate structural reusability. Even though the report focus is on single-story buildings made of steel, it also shows on a general level, ways to handle practical issues regarding reuse of concrete structures.

In this paper, connections between precast concrete structures are reviewed for their fit to enable the dismount and reuse of structures. Existing solutions must agree with the current norms recognizing the reuse and their potential must be proven in practice. Benefits of reuse are also assessed from economic and environmental standpoints by presenting a study case for load-bearing structures of precast concrete frame.

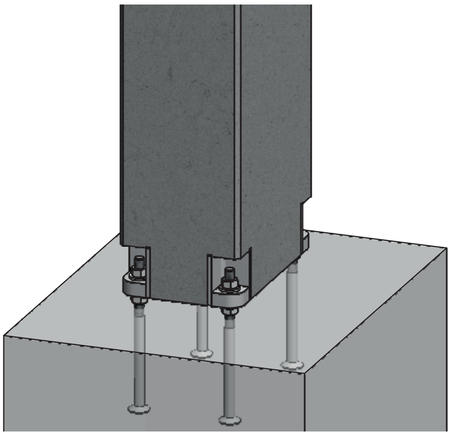


FIGURE 1. TYPICAL PRECAST COLUMN CONNECTION [8]

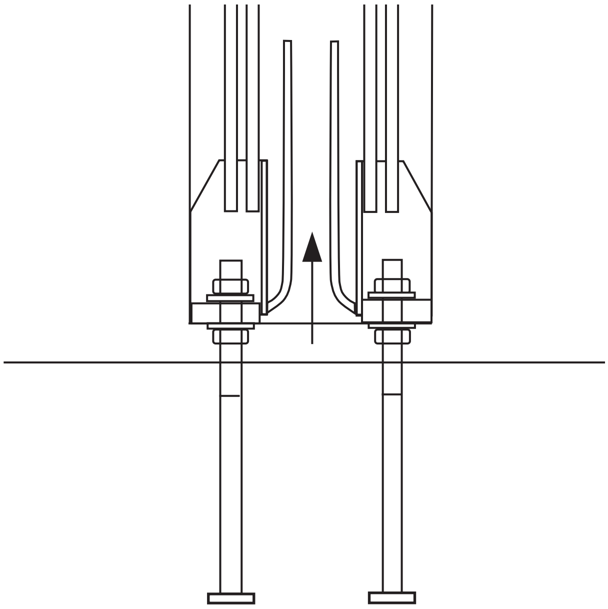


FIGURE 2. LEVELLING OF PRECAST COLUMN

DESIGN-FOR-DISASSEMBLY (DFD)

Design-for-Disassembly is a building process that allows the easy recovery of the products, parts, and materials, when a building itself is deconstructed. The process is intended to maximize economic value and minimize negative environmental impact through reuse, for instance. The design of the construction components, in the meaning of DfD, requires ensuring the diverting from the waste stream [7].

The current design practices need to be refreshed to take into account the key properties of DfD. The structural design of the building should consider the disassembly and how to access the components by relatively easy means. These same key properties should be considered also in the design of the building products, but one must pay attention to the selection of the raw materials as well, which should last and be recyclable. Currently, the buildings are designed to be demolished and their materials recycled or even disposed as an end solution. Sometimes, this happens much earlier than designed lifespan of the building, which means that construction components and materials still have clear residual value. Especially in those cases, implementing the DfD would provide significant economic and ecological benefit.

Design-for-Disassembly is not yet implemented to legislations or current design practices. Nevertheless, it is noted in Green Building certifications like BREEAM and DGNB and may offer extra credits with good implementation. Currently, ISO 20887 [7] seems to be the only international standard to provide a practical overview of DfD.

BOLTED CONNECTIONS

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

Bolted connections are one of the most common ways to connect precast structures on site with numerous practical benefits. Bolted connections further improve the competitiveness of precast structures by allowing time-saving installations without a high amount of effort or manpower. Typical precast concrete column connected to foundation with bolts is presented in figure 1.

In the research report by Lahdensivu et al. [9], it is concluded that adequate connections are the key for unlocking the reuse potential of precast concrete structures, and those should be designed to enable cost-efficient dismount without compromising with the other required properties.

When building with precast concrete elements, certain installation tolerances are usually required at the construction site. That is often realized as a gap between the connected structures. One good example is the connection between the column and the foundation, where the column must be levelled in vertical direction after installation (**figure 2**). The gap between the structures must be grouted with cement-based mortar, which has sufficient strength for load-transfer through the joint. However, cement-based grout is known to create an adhesive bond with the connected structures. Initially, this bond between fresh and old concrete is considered as one of the key challenges for allowing the easy and efficient dismount of precast concrete structures.

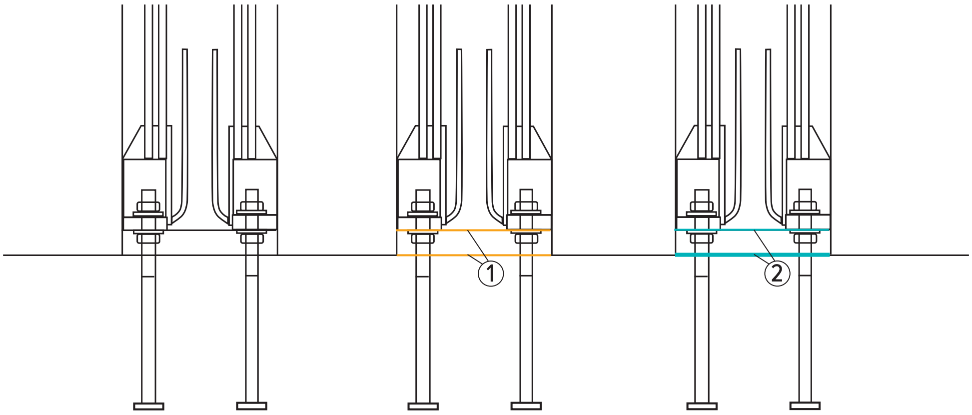


FIGURE 3 DETAILS OF TEST SETUPS

STUDY CASE 1: DEMOUNTABILITY OF PRECAST COLUMN CONNECTIONS

Bolted connections already have a lot of potential to work as demountable, since opening of the connection is equally easy as fixing in principle. Encouraged by the potential of bolted connections, the authors have performed demountability tests for precast columns connected with precast foundation blocks.

Demountability tests took place in November 2019, which included the assembly, disassembly, and reassembly of three different bolted column connections (see **figure 3**).

- traditional precast column connection without release agent
- developed demountable connection with demolding oil as release agent(1)
- developed demountable connection with thin plates as release agent(2)

While traditional column connection was formed with common M16 anchor bolts, two other connections with release agent were formed with M16 anchoring couplers and threaded bars. All connections were grouted with cement-based mortar after assembly. Release agents, as treatments of joint faces, were used to prevent adhesive bond between the precast structures and the grout. The scope of the tests was to show that using the common cement-based mortar as grout material is not a problem for dismount of the connection.

FIGURE 4. CASTED FOUNDATION BLOCKS INSIDE THE GROUND

Tests were performed in three different phases. In the first phase, foundation blocks were casted into the ground and equipped with designated set of anchor bolts and anchoring couplers. Hardened foundation blocks are presented in **figure 4**. To ensure a proper development of strength under winter conditions, heating cables were also installed inside the casting molds.

In the second phase, identical precast columns were connected with hardened foundation blocks. As explained, the connection with common M16 anchor bolts did not involve any kind of release agent and joint faces of two other connections were treated with demolding oil and thin steel plates. Oiled joint faces and installation of the precast column is presented in **figure 5**.

FIGURE 5. DEMOUNTABLE CONNECTION WITH DEMOLDING OIL AS RELEASE AGENT

After the assembly of precast columns, gaps between the structures were grouted with cement-based mortar and left to harden.

In the third and the last phase, all connections were dismounted by opening the upper nuts of threads, and columns were removed from hardened grout pad. In addition to the dismount of the connections and removal of the precast columns, the ambition was to show that also foundation blocks can be reused as such. Threaded bars in developed demountable connections were removed from anchoring couplers through hardened grout pads, as shown in **figure 6**.

FIGURE 6. REMOVING THE THREADED BARS FROM ANCHORING COUPLERS

While removal of the grout pad was faster and easier for connections with release agents, the pad of the traditional connection was also found removable, requiring the use of demolition hammer and saw-cutting (see **figure 7**). Consequently, also the conventional column base connection was found reusable. In the end, removed precast columns were reassembled and all connections were reformed by grouting.

FIGURE 7. REMOVAL OF GROUT PAD WITHOUT RELEASE AGENT

STANDARD REQUIREMENTS

Number of current standards recognizing the dismount and reuse of structures is currently very thin. One of the few is ISO 20887:2020 [7] where reuse is defined as use of products or components more than once for the same or other purposes without reprocessing. The reprocessing does not include preparation for reuse, such as cleaning etc. Basically, the construction component should be fit for use in another building without major repairs or modifications.

As stated earlier, the reuse of the old, existing structures could be a powerful tool for solving the current problems of high CO_2 emissions and raw material consumption, which have been stigmatizing the construction industry. When construction components are disassembled and reused, their total value is preserved not only from economic but also from environmental standpoint. The same components can be sold more than once to reduce their carbon footprint. Reusing also has a positive impact on the usage of the virgin raw materials and the overall production of the new components, so that they are not consumed as such. To enable the future reuse of new construction components, their connections must be designed as demountable by following the principles of DfD.

Principles of ISO 20887:2020 [7] apply to assemblies and systems within a constructed asset that can be disassembled at the end-of-life, or renovated, with the potential for components to be reused for other purposes.

The disassembly principles that shall be considered are as follows:

a) ease of access to components and services
b) independence
c) avoidance of unnecessary treatments and finishes
d) supporting reuse (circular economy) business models
e) simplicity
f) standardization
g) safety of disassembly

The practices that can support the principles:

a) When possible, materials and components, which can be easily, safely, and more cost effectively replaced or removed and transported, should be used.
b) A means of handling components during disassembly should be provided. Handling during disassembly can require connection points for lifting equipment or temporary supporting devices.
c) Components that are sized to suit the intended means of handling should be used. Various possible handling options at all stages of assembly, disassembly, transport, reprocessing, and reassembly should be considered.
d) Spare parts, and on-site storage for them, should be provided. Particularly for custom designed parts, to allow broken or damaged components to be easily disassembled and replaced, and to facilitate minor alterations to the design.

REVIEW OF BOLTED CONNECTIONS BASED ON STANDARD REQUIREMENTS

Even though the practical tests showed that bolted precast column connections can be disassembled, a quantitative and qualitative analysis of demountability seems to be a tricky exercise, considering that the number of scientific references and industrial standards dealing with the topic is relatively thin. For this reason, the authors will limit themselves to describe how the observed properties of the tested assemblies comply with the general principles formulated in ISO 20887 [7].

EASE OF ACCESS TO COMPONENTS AND SERVICES

The most essential feature of the dismount is to get access to the bolted connection located between the column and the foundation. This is ensured by leaving the recess boxes of column shoes exposed during the grouting of the joint and filling them with removable insulation material instead (see **figure 8**). The insulation material does not need to be load-transferring, but it must be able to provide sufficient protection at least against fire. There may be several alternatives with such properties, like some lime mortars [10] and sprayable insulations [11].

INDEPENDENCE

Independence means that structures should be possible to dismount by minimizing the effect on the performance of the connected or adjacent building components. Maximizing independence of the functional requirements of parts, components, modules and systems is key for optimizing disassembly for both reuse and upgrade. Materials or components should be removable without disrupting other components or materials. Where this is not possible, the most reusable parts of the assembly should be made the most accessible, to allow for maximum recovery of those components [7].

Precast columns can be considered as one of the most reusable parts of precast concrete frame, since their dimensions, like cross-section and height, are highly repeatable in many different buildings. Thus, precast column removed from the original building might be easily used second time in some other building without significant reprocessing. Accessibility of column can be achieved by enabling the dismount between column and foundation, as well as beam and column. As mentioned, access to the connection between column and foundation can be ensured by using removable material in the recess boxes of the column shoes. Bolted connection is also the most favorable solution to be used between the beam and the precast column. When using precast beams or beams casted in-situ, demountability can be provided by using plastic or steel pipes as presented in **figure 9**.

AVOIDANCE OF UNNECESSARY TREATMENTS AND FINISHES

Precast concrete structures should be designed to have long service life and their exposed steel parts should be protected well enough against environmental exposure. Anchor bolts could be eco galvanized or treated by other means when supplied to the construction site. By providing such coatings for steel parts, less requirements are needed when choosing the insulation material for exposed bolted connections.

SUPPORTING REUSE (CIRCULAR ECONOMY) BUSINESS MODELS

Reusability of components provides the benefit and motivation for dismount. Possibility for using “old” components for new buildings to reduce the need for manufacture of new components, which would be effective way of cutting high CO_2 emissions and reducing the consumption of raw materials. Bolted connections are the key for reuse of precast structures due to their reversibility.

Effective and controlled reuse of old building components may require a totally new form of Circular Economy business model where dismounted structures would be acquired, stored, and sold by dedicated suppliers. These companies, either private or owned by the government, would buy used building components from demolition sites and retail them to buyers. In order to sell old and used building components, suppliers should provide browsable market stock with relevant information including materials, dimensions and fit of each component.

SIMPLICITY

The quality of an assembly or system that is designed to be simple and straightforward, easy to understand and meets the performance requirements with the least amount of customization [7].

While assembly of conventional bolted connection between the precast structures is known to be fast and effortless, modifications for demountable bolted connection are not that significant (see **figure 9**). Use of release agent is the only part bringing some additional complexity but treating of the joint surfaces can be done before column assembly and does not require exceptional on-site actions. However, first demountability tests with precast columns showed that the use of release agent is not crucial for reuse of precast structures.

STANDARDIZATION

Column shoes and anchor bolts for the connections of the precast structures are highly standardized parts, which allow use of repetitive techniques for both assembly and disassembly. Connections can be also formed and dismounted by using basic tools and small amount of resources.

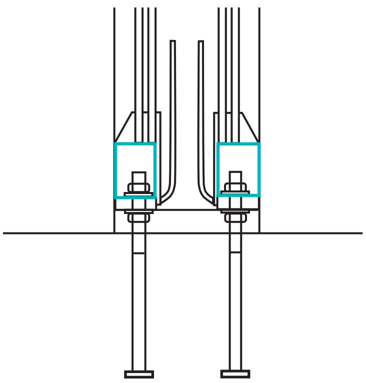


FIGURE 8. HIGHLIGHTED RECESS BOXES

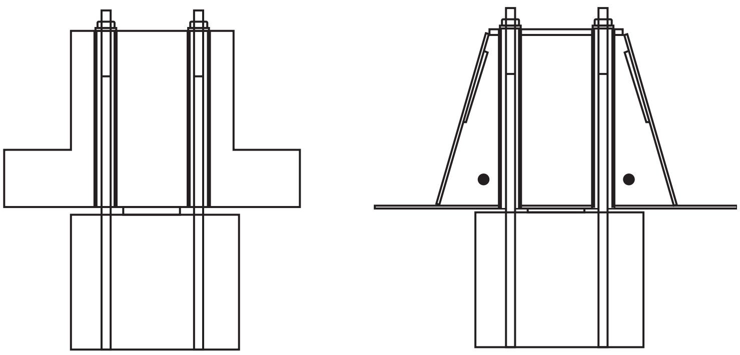


FIGURE 9. DEMOUNTABLE CONNECTIONS BETWEEN THE COLUMN AND RC BEAM (LEFT) OR COMPOSITE BEAM (RIGHT)

In order to convert dismount and reuse into standardized procedures, there should be an effective way to handle relevant data (the properties of the structure, age, etc.). This could be provided by data labelling, for example in a form of QR codes. When a structure would de dismounted and stored waiting for the next use, relevant data could be read from the QR code and stored in the data bank (browsable data for clients).

SAFETY OF DISASSEMBLY

Accessible and highly reversible bolted connections allow fast and safe disassembly without risking that the structures would fall during the dismount process. Temporary propping of load-bearing structures, such as beams and columns, must be carefully considered before starting the dismount process. Structures should also be removed in reasonable order to reduce the amount of risks and probability of unpredictable accidents.

STUDY CASE 2: DISMOUNT AND REUSE OF PRECAST CONCRETE FRAME

The most significant finding from the demountability tests of precast columns was that in-situ grout between precast structures is not preventing dismount and reuse. Inspired by the success of the first demountability tests, the authors decided to proceed to a larger scale. The new test involved steel concrete composite Frame Structure.

The tests took place between November and December of 2021 and were conducted in three phases. Phase one involved assembly of the concrete and the steel-concrete composite components into a frame at the site and grouting of the connection joints. In the second phase, the whole frame was disassembled into original parts, and in the last phase, the frame was reassembled. 3D model of the frame is presented in **figure 10**.

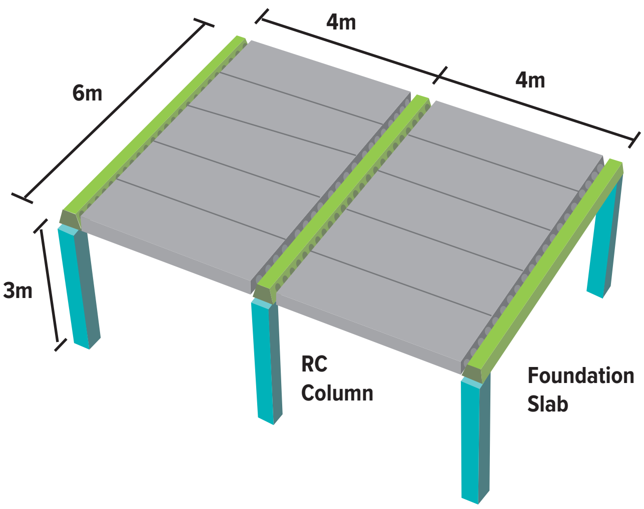


FIGURE 10. 3D MODEL OF THE FRAME

The foundation had already been prepared with post-installed anchor bolts. The total area of the foundation slab was measured as 88 m^2. Details of the load-bearing components of the frame were as follows:

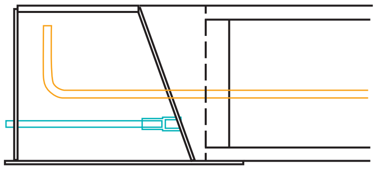
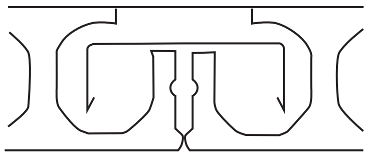
Component	Dimensions	Number	
Precast Columns	350x350x3000	6	
HC slab units	320x1200x3520	10	
DELTABEAM® Green	D32-400/DR32-365 (L=6090)	3	

Two different types of floors were tested. On the other side, joints between adjacent HC slab units and DELTABEAM® Green were reinforced and grouted as usual (Type 1). Integrated MODIX® coupler bars for reassembly phase were the only significant modification, when compared to conventional solution.

On the other side, the amount of in-situ grouting was minimized by using "dry" joints, where mechanical connectors were used for beam-to-slab connections and joints between adjacent HC slabs were grouted only locally (Type 2). With Type 2 connections, reusability of slabs was provided by involving a double amount of mechanical connectors and locally grouted joints but using only half of them in the first assembly phase.

In-situ concrete of DELTABEAM® Green composite beams was separated from joint concrete by covering the beam web holes with welded steel plates. That was meant to ensure that beam infill concrete (crucial for load bearing) is not damaged during the dismount process. Instead of using welded steel plates, lighter applications could be considered (e.g., plastic plugs). Covering the web holes may have influence on flexibl shear in HCs units and a proper study should be carried out before applying this in real projects.

Details of the connections between load-bearing components were as follows:

Connection	Type	Number	
Column-to-foundation	Post-installed anchor bolts	6	
Beam-to-column	Anchor bolts	6	
Slab-to-beam (Type 1)	Reinforced "wet" joint	10	
Slab-to-beam (Type 2)	"Dry" joint	10	 
Slab-to-slab (Type 1)	Reinforced "wet" joint	4	
Slab-to-slab (Type 2)	"Dry" joint	4	

FIRST ASSEMBLY

In the first assembly phase, all load-bearing structures were assembled and connected. Structures were lifted with the on-site crane operator. Assembled frame is shown in **figure 11.** The setup was left to set and harden for over a month before starting the second phase.

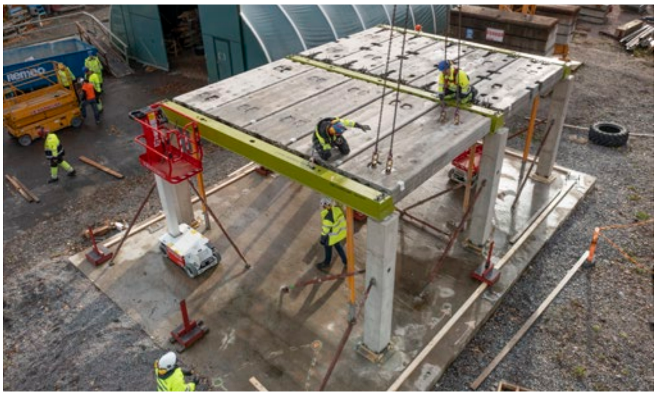


FIGURE 11. ASSEMBLED PRECAST FRAME

FIGURE 12. DISASSEMBLY OF GROUTED SLAB JOINTS AND REMOVAL OF HC SLAB UNIT

DISASSEMBLY

The frame was dismantled systematically using a crane. The process was the reverse of the assembly phase. The first step was to dismount the HC slab units. For the conventional "wet" joint, the concrete joint was initially cut using a diamond saw, as shown in **figure 12**. Then the HC slab units were lifted off and carefully stored aside.

For the "dry" joint, the joints were dismounted by opening the nuts of mechanical box connectors. Whenever there was concrete (where the rebars were concreted into place in the precast concrete slab), a diamond saw, and chipping hammer were used to remove the grout (see **figure 13**).

Step two was to dismount the beams. This was an easy task with disassembling the connections by opening the nuts from the anchor bolts and carefully lifting the beams off the columns (see **figure 14)**.

FIGURE 13. REMOVING OF CONCRETE BY USING A CHIPPING HAMMER

FIGURE 14. DISASSEMBLY OF DELTABEAM® GREEN COMPOSITE BEAMS

The last step involved dismounting the precast columns. This was done by dismounting the bolted connections, lifting the column off the hardened grout pad, and removing the hardened grout pad off the foundation. See **figures 15, 16** and **17** below.

FIGURE 15. OPENING THE NUTS

FIGURE 17. CLEANED FOUNDATION READY FOR REASSEMBLY OF PRECAST COLUMN

FIGURE 16. REMOVING THE GROUT PAD

REASSEMBLY

The main aim of the test was to demonstrate demountability of the composite frame, and the reuse of the load-bearing components. Having succeeded in retrieving all the components in the disassembly phase, the reassembly phase involved the reuse of the components. The construction process was similar to the first assembly, requiring the cleaning of some structural components (voids and sides of HC slab units). The cleaning process involved removing of any residual concrete that had been used in the joint creation. This was done with a hand operated demolition hammer (see **figure 18**).

Reassembly of precast columns, DELTABEAM® Green and HC slab units are shown in **figures 19**, **20** and **21**.

Consequently, it was concluded that all structural components were reusable and able to serve at least the second time from their connection standpoint.

FIGURE 18. CLEANING PROCESS OF VOID AND CLEANED VOID OF HC SLAB UNIT

FIGURE 19. REASSEMBLY OF PRECAST COLUMNS ON THE FOUNDATION SLAB

FIGURE 20. REASSEMBLY OF HC SLAB UNITS ON DELTABEAM® GREEN, “WET” JOINT ON THE LEFT AND “DRY” ONE ON THE RIGHT

FIGURE 21. REASSEMBLY OF DELTABEAM® GREEN COMPOSITE BEAMS ON PRECAST COLUMNS

BENEFITS OF DISMOUNT AND REUSE

Even if load-bearing structures of precast concrete frame can be considered as demountable and reusable, it has no practical value, unless there is either a significant economic or environmental benefit. In this chapter, economic and environmental influence of the frame as the study case is assessed by comparing it with geometrically similar frame without considered demountability (conventional frame).

Comparison is made at three different levels: parts and materials, processes, and new building. While the economic impact is defined by assessing the price (€) of different parts and structures, the environmental impact is defined by calculating the carbon footprint (kgCO_2).

The basis for calculations is presented in **table 1**. The economic indicators include the freight of 100 km, and the environmental indicators are defined by considering Cradle to gate with options, which includes information modules A1-A3, A4, C1-C4 and D [12].

The following contributions have been excluded from this study

- installation of structures (crane operations and on-site installations)
- demolition process (conventional frame)

Structure	Economic indicator	Environmental indicator	Source for economic impact	Source for environmental impact
DELTABEAM® Green	620 €/pc	1.31 kgCO_2-eqv/kg	Supplier[1]	EPD DELTABEAM® Green Finland [13]
Precast columns	2000 €/m³	442.53 kgCO_2-eqv/m³	Supplier[2]	EPD TB-Suorakaidepilari [14]
Hollow core slabs	50 €/m²	46.42 kgCO2-eqv/m2	Supplier[2]	EPD Low carbon hollow core slab [15]
Steel parts	vary*	1.27 kgCO_2-eqv/kg	Supplier[1]	EPD Connecting parts [16]
In-situ concrete (pumped)	130 €/m³	238.52 kgCO_2-eqv/m³	Supplier[3]	EPD Generic ready mixed concrete [17]

Supplier[1]: Peikko Finland, Supplier[2]: Parma Consolis, Supplier[3]: Rudus

TABLE 1. BASIS FOR ECONOMIC AND ENVIRONMENTAL IMPACT OF STRUCTURES

*There were two additional steel parts, and their economic impacts are listed here.

- MODIX® coupler bar 11 €/pc
- Steel box connector 75 €/pc

Similar table was created for different dismount processes, requiring funds and energy (see **table 2**).

Structure	Economic indicator	Environmental indicator	Source for economic impact	Source for environmental impact
Saw-cutting	30 €/m	0.23 kgCO_2-eqv/kWh	Supplier[1]	OneClick LCA tool [18]
Piking	35 €/h	0.23 kgCO_2-eqv/kWh	Supplier[2]	OneClick LCA tool [18]

Supplier[1]: Gles Oy, Supplier[2]: Peikko On-Site Service Oy

TABLE 2. BASIS FOR ECONOMIC AND ENVIRONMENTAL IMPACT OF PROCESSES

PARTS AND MATERIALS

In general, the demountable frame required some additional steel parts, which are listed in **table 3**. Since there were two alternatives for providing the demountability: "dry" and "wet" joints, the following distinction was made: "dry" = red and "wet" = blue. The economic and environmental impacts of steel parts integrated to DELTABEAM® Green composite beams are not studied separately but their influence was taken into account in terms of the weight and price of the beams. Their influence on total price and carbon footprint of DELTABEAM® Green is also relatively insignificant. Joint reinforcement of demountable frame with "wet" joints and conventional frame are excluded from the study as a simplification. Total economic and environmental costs of the parts and materials are calculated and presented in **table 3**.

Structure	Economic measure	Environmental measure	Price €	Carbon footprint $kgCO_2$
DELTABEAM® Green	3 pcs	1 584 kg	1 860	2 075
Precast columns	2.21 m^3	2.21 m^3	4 400	974
Hollow core slabs	42.2 m^2	42.2 m^2	2 110	1 959
Steel box connectors	40 pcs	288 kg	3 000	366
MODIX® B Coupler bar	14 pcs	17.5 kg	154	22
In-situ concrete (beams)	2.17 m^3	2.17 m^3	286	525
In-situ concrete (joints)	0.75 m^3	0.75 m^3	98	179
Total			**8 754**	**5 712**
Total			**8 908**	**5 734**
Total			**11 656**	**5 899**

TABLE 3. ECONOMIC AND ENVIRONMENTAL COSTS OF PARTS AND MATERIALS

Total amounts in **table 3** refers to the following frame solution. The coloring logic is used also in **tables 4**, **5** and **6**.

Total Total price and carbon footprint of conventional frame
Total Total price and carbon footprint of demountable frame with "wet" joints
Total Total price and carbon footprint of demountable frame with "dry" joints

"WET" JOINTS

The difference between demountable frame and frame without considered demountability is governed by additional steel parts for demountable DELTABEAM® Green – hollow core slab interface. Additional MODIX® parts are presented in **figure 22**. MODIX® A was integrated to DELTABEAM® and MODIX® B is attached to it and anchored to the joint between adjacent HCs units. Total weight of the part B was about 1.25 kg (length of one rebar 800 mm). If the whole frame would have been executed with "wet" joints, total amount of rebars with MODIX® B would be 14 pcs.

"DRY" JOINTS

Demountable alternative with "dry" joints required less concrete grouting than frame without considered demountability. However, connection between hollow core slabs and Deltabeams was fixed with special steel box connectors (see **figure 23**), which have total weight of 7.2 kg. If the whole floor would have been executed with "dry" joints, total 40 pcs of steel box connectors would be needed.

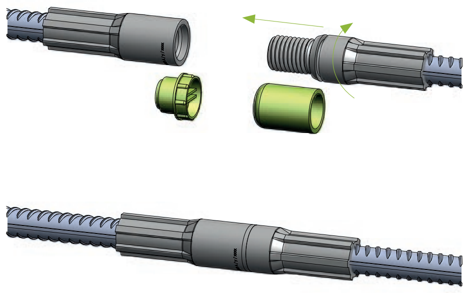


FIGURE 22. PRINCIPLE OF MODIX® CONNECTION

FIGURE 23. STEEL BOX CONNECTOR

PROCESSES

Dismount and reuse processes of the demountable frames must be compared to demolition process of the frame without considered demountability. Considerable dismount and reuse processes (processes to prepare structures for reuse) can be split to saw-cutting and piking of hardened concrete. Crane operations for lifting the dismounted structures, as well as demolition processes, are excluded from this study, since they are considered to compensate each other. While dismounting the floor with "wet" joints required the most of saw-cutting, only short pieces of grout had to be cut in case of "dry" joints. Bond between painted DELTABEAM® Green surface and concrete grout appeared to be very poor and almost no effort was needed for removing the hardened grout from beam. Total economic and environmental costs of processes are calculated and presented in **table 4**.

Process	Economic measure	Environmental measure	Price €	Carbon footprint $kgCO_2$
Saw-cutting	55 m	31.4 kWh	1 650	7
Piking	16.7 h	33.4 kWh	585	8
Piking	0.7 h	1.4 kWh	25	~0
Total			**0**	**0**
Total			**2 235**	**15**
Total			**25**	**~0**

TABLE 4. ECONOMIC AND ENVIRONMENTAL COSTS OF PROCESSES

SAW-CUTTING

If the floor would have been executed only with "wet" joints, total amount of grouted joints would be about 55 m. It was measured during the disassembly process, that saw-cutting took about 10 min/m, if a blade split the longitudinal joint reinforcement and 2.5 min/m, if only concrete was cut. As a result, if the blade would split the longitudinal joint reinforcement in every joint, required time for saw-cutting would be 550 min (9 hours and 10 minutes) and if the blade wouldn't hit the longitudinal joint reinforcement, it would take 138 min (2 hours 18 minutes) instead.

Similarly, the power of the cutting machine was about 1.35 times greater, when the longitudinal joint reinforcement was cut in half. According to the saw-cutting company, the maximum size of the fuse was 25 amperes, which defined the maximum input power (W). By assuming the average line current in Finland (230 V), the maximum power of saw-cutting machine can be assessed as follows:

Concrete $P = (U * I)/1.35 = 4260\ W$ (1)

Longitudinal rebar $P = U * I = 5750\ W$ (2)

where U = 230 V as a line current and I = 25 amperes as the size of fuse. The total energy consumption for saw-cutting can be calculated based on required time.

Concrete $E = P * 2.3\ h = 9.8\ kWh$ (3)

Longitudinal rebar $E = P * 9.2\ h = 52.9\ kWh$ (4)

An average value (31.4 kWh) will be used for further comparison.

PIKING

Demolition hammer was needed for removing the joint concrete between precast columns and foundation slab. In addition, hollow core slabs with "wet" joints had to be cleaned (sides and voids) by piking in order to allow the reuse of slabs. The measured time of cleaning the slab units (sides and voids) was about 1.6 h/slab unit and the time of cleaning the joint between the precast column and the foundation slab was about 7 min/joint. If the whole floor had been executed with "wet" joints, the total of 16 hours (from one site worker) would have been required for cleaning all slabs and 0.7 hours for cleaning all joints between the columns and the foundation slab. Different suppliers informed us that power of the pike machine equals about 1500–2000 W. It means that the total amount of energy needed for reuse processes would be as follows:

"Wet" joints $E = 16.7\ h * 2000\ W = 33.4\ kWh$ (5)

"Dry" joints $E = 0.7\ h * 2000\ W = 1.4\ kWh$ (6)

NEW BUILDING

In case of demolition, a new building cannot be built without producing new similar structures. However, all structures were found as reusable in demountable precast frame. Costs of reforming the conventional frame are calculated and presented in **table 5**.

Structure	Economic measure	Environmental measure	Price €	Carbon footprint $kgCO_2$
DELTABEAM® Green	3 pcs	1 584 kg	1 860	2 075
Precast columns	2.21 m^3	2.21 m^3	4 400	974
Hollow core slabs	42.2 m^2	42.2 m^2	2 110	1 959
In-situ concrete (beams)	2.17 m^3	2.17 m^3	286	525
In-situ concrete (joints)	0.75 m^3	0.75 m^3	98	179
Total			**8 754**	**5 712**
Total			**0**	**0**
Total			**0**	**0**

TABLE 5. ECONOMIC AND ENVIRONMENTAL COSTS OF THE NEW BUILDING

COMPARISON

Finally, estimated economic and environmental costs of different frames can be added and compared (see **table 6**).

Frame type	Parts and materials		Processes		New building	
	Price €	Carbon footprint $kgCO_2$	Price €	Carbon footprint $kgCO_2$	Price €	Carbon footprint $kgCO_2$
Conventional	8 754	5 712	0	0	8 754	5 712
Demountable 'wet'	8 908	5 734	2 235	15	98	179
Demountable 'dry'	11 656	5 899	25	0	0	0

TABLE 6. COMPARISON BETWEEN ECONOMIC AND ENVIRONMENTAL COSTS OF DIFFERENT FRAMES

As a result, the total prices and carbon footprints are as follows:

Conventional	**17 508 € (100%)**	**11 424 $kgCO_2$ (100%)**
Demountable "wet"	**11 241 € (64%)**	**5 928 $kgCO_2$ (52%)**
Demountable "dry"	**11 681 € (67%)**	**5 899 $kgCO_2$ (52%)**

CONCLUSIONS

The amount of current standards recognizing the dismount and reuse of structures is found very thin. One of such standards was presented in the paper, and the bolted connections agree with the principles of the standard [7]. However, there is a need for new standards dealing with the topic, which would also help to verify the condition of old concrete structures for reuse.

The performed demountability tests of the precast column base connections and precast frame have shown that load-bearing structures can be dismounted and reused as such from their connection standpoint. In-situ grout between the connected structures does not create such obstacles for dismount as it had initially been considered by the authors. It should be also pointed out that reprocessing and reusing HCs units as such is currently forbidden in some European markets (e.g., Germany). However, to make the dismount and reuse an everyday practice changes are required not only in structural solutions, but also at much higher level. This concerns, for example, regulation based limitations for concrete structures which may oppose the reuse.

The economic and environmental cost estimation, which was performed for the study case, shows that there are both economic and environmental benefits and motivation to consider demountability as a design aspect. In the study case, demountable frames appeared as 35% cheaper and having about 50% less environmental load than conventional frames, when construction of a new building is required.

Even though the demountable frame with "wet" joints requires more work both in terms of assembly and disassembly than the frame with "dry" joints, the other crucial functions of the floor (load transfer, robustness) are not significantly jeopardized. In the case of the "dry" joints, the performance of the floor should be further studied, and compromises might be necessary.

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