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DOI
10.1007/978-3-031-45980-1_4

Publication date
2023

Document Version
Final published version

Published in
Creating a Roadmap Towards Circularity in the Built Environment,

Citation (APA)
Kavoura, F., & Veljkovic, M. (2023). Design Strategies and Technical Practices for Reusable Steel–Concrete Composite Structural Systems. In L. Bragança (Ed.), *Creating a Roadmap Towards Circularity in the Built Environment,* (pp. 39-46). (Springer Tracts in Civil Engineering; Vol. Part F1844). Springer. https://doi.org/10.1007/978-3-031-45980-1_4

Chapter 4
Design Strategies and Technical Practices for Reusable Steel–Concrete Composite Structural Systems

Florentia Kavoura and Milan Veljkovic

Abstract The technical solutions and design strategies for deconstruction are reviewed and investigated in the building sector in order to achieve the sustainability goals set in the EU Commission´s "Green Deal" towards net zero greenhouse gas emissions by 2050. The demountable and reusable steel–concrete composite structures could contribute immensely to the achievement of these sustainability goals. The main technical practice which allows for demountability and reusability is the use of bolted connections on the skeleton of the steel structure with the parallel use of demountable shear connectors in their floor systems with the steel load-bearing beams. However, there is a very limited number of studies and methods into specific demountable and steel–concrete composite structural systems, and even fewer focus on their practicability and feasibility. Since these systems have the potential to reduce embodied carbon impacts, encourage resource efficiency and, reduce construction waste, their feasibility and technical practices should be investigated. This paper focuses on technical solutions and design strategies that currently have been developed for steel and steel–concrete composite reusable structural systems.

Keywords Demountable shear connectors · Reusability of composite floors · Sustainable structural design

4.1 Introduction

The structural design for deconstruction is estimated that it is going to contribute considerably to the sustainable development of the built environment [1]. In response to the sustainability requirements set in the EU Commission´s "Green Deal" [2] towards reduction of the greenhouse gas emissions the preferred strategy in order to achieve a sustainably built environment is to design for demounting, and reuse of

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L. Bragança et al. (eds.), *Creating a Roadmap Towards Circularity in the Built Environment*, Springer Tracts in Civil Engineering,
https://doi.org/10.1007/978-3-031-45980-1_4

the components before thinking about repair, remanufacturing, or recycling. Consequently, to follow Cramer's [3] structural scheme on how a circular economy can be incorporated for sustainable construction.

Therefore, the aim for a sustainable design needs to focus on material-efficient use and the production of layouts that allow a whole or partial structural component to be reused and achieve longer structural life spans [4]. With respect to efficient material use, the research is directed toward the use of multi-material structural components. With these components, we could achieve optimum material use by combining the advantages of mechanical properties of different construction materials (e.g. concrete in compression and steel in tension). The main focus areas in the construction sector are the demountability and reuse since they allow the potential for cost reduction in extended life cycles, for value retention of the structural members, a smaller environmental impact and consequently enhancing sustainable construction. Current developments of the steel–concrete composite structures underline their advantages with respect to their speed of construction, the decrease of the self-weight of the structure, and achieve larger floor span when compared with other types of structural systems (e.g. reinforced concrete) [1]. The demountability of steel–concrete composite systems addresses the need for composite interaction while in parallel enabling the non-destructive separation of the steel beam and the concrete floor as shown in Fig. 4.1. This separation can be achieved with the aid of demountable bolted connectors which have shown that they can provide the necessary shear connection that the traditional construction method with the welded shear studs can also achieve. Some types of demountable connectors are presented below.

Several connectors have been investigated (see Fig. 4.2) in the literature and include friction-based shear connectors [5, 6], bolted-headed studs with embedded nuts [7, 8], and embedded coupler shear connectors [9–11]. The former type of demountable shear connectors are bolts filled with a two-component epoxy resin from their head and has been researched in feasibility and large-scale application levels [9, 10]. These injection bolts are used in shear connections where slip should be avoided, as an alternative for fitted [12] or pretension bolts. In this paper, this technical practice will be discussed in Sect. 4.3, on component and structural system levels through research that has been performed at the Delft University of Technology and is part of the RFCS project "REDUCE" [22].

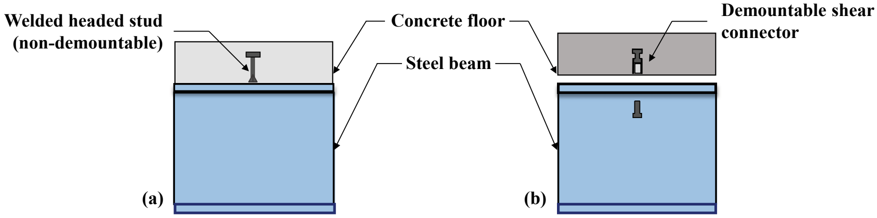

Fig. 4.1 The technical solution of the replacement of the **a** welded-headed studs with **b** demountable shear connectors in order to enable the reuse of the steel–concrete composite floors [13]

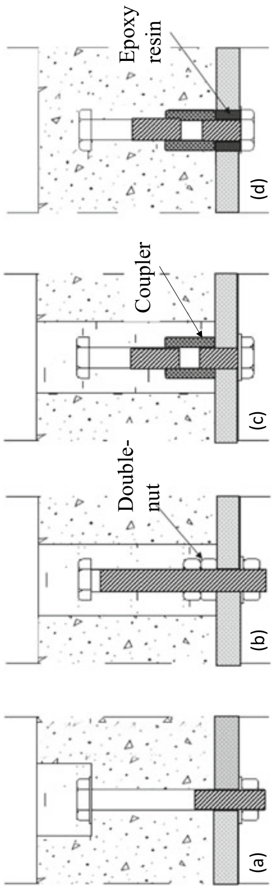

Fig. 4.2 Types of demountable bolted connectors **a** friction grip bolts, **b** double-nut, **c** coupler system connectors, **d** injected bolted shear connectors with a coupler system

4.2 Design Strategies for the Re-Use of Steel Structures

The approach for the reusability of reclaimed steel structural components is discussed in detail within the RFCS project Progress [14] and SCI [15] documents. They mainly focus on the design for deconstruction of one-story steel buildings where the in-situ and relocated reuse scenarios are examined thoroughly. According to the described processes, the procedure for the reuse of reclaimed steel structural elements is described in Fig. 4.3. The first phase includes the pre-deconstruction audit and assessment for reuse, which include a preliminary overall visual inspection (e.g. identifying problems such as excessive corrosion, excessive/plastic deformation of the structural elements, etc.) and quantitative/empirical evaluation and reporting (e.g. dimensions of joints and their connectors, etc.) of the existing steelwork. The second phase includes the sampling and testing techniques that quantify the material properties and verify the structure. The testing programs include a range of destructive (DT) (e.g. tensile testing, chemical composition analysis, charpy impact test) and non-destructive (NDT) tests (e.g. hardness tests, positive metal identification, and small punch testing). The third phase covers the design for reuse and the design considerations for achieving a reliable structure with reclaimed steel elements and structural analysis principles according to EN 1993 provisions.

4.2.1 Re-Used Steel Structural Elements in Practice

Real-life examples that address nowadays the reusability of buildings like "Donorskelet" [16], bridges like the "Nationale Bruggenbank" [17], or platforms that create digital databases on reclaimed steel structural elements like the "Circulair Bouwen in 2023" [18] are supported in the Netherlands. Also, several real-life case studies mainly in industrial one-story buildings are presented in detail in the RFCS project Progress [14] and illustrate the use of reclaimed steel structures in various EU countries. Through these case studies, the technical viability of the reuse of steel reclaimed elements is confirmed. The significant barriers across the supply chain have been identified as the additional time/program and cost of using reclaimed steel. However, several advantages in terms of environmental and economic benefits

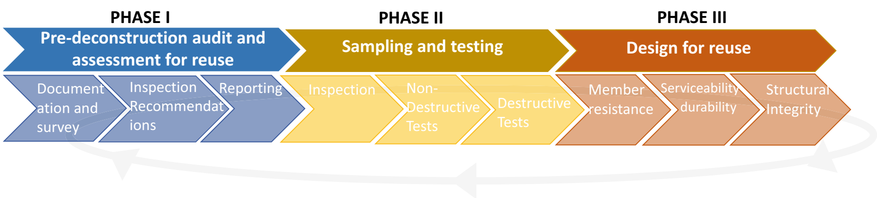

Fig. 4.3 Methodology of reusing a structural component into a new structure based on the circular building environment according to the RFCS project Progress [14]

have been underlined by the use of reclaimed steel structural elements [1, 15, 17]. Overall, as future goal is then that the required information about the reclaimed steel elements will be included in a material passport, which will be presented in digital databases for easy access [19].

4.3 Technical Solutions for Reusable Steel–Concrete Composite Structural Systems

The feasibility and the performance of demountable and reusable structural systems have been studied at Delft University of Technology through experiments on prefabricated composite floor systems which were designed to replicate a typical car park building [9] and experiments on cast-in-situ composite slabs [10]. The physical assemblies in the laboratory environment can be seen in Fig. 4.4. The demountable connectors used in both studies are the injected bolted shear connectors with a coupler system presented in Fig. 2d. The embedded and injection bolts were M20 grade 8.8 while the coupler was M20 and grade 10.9 and the injectant epoxy was the RenGel SW 404/2404. The load-bearing resistance of these injected bolts is substantially higher than its uniaxial compression strength due to the natural confinement provided by a bolt hole [20] caused by the injected epoxy resin acting as a load-bearing element. The benefit of the injected bolted shear connectors is that they allow for oversized holes which can account for the fabrication and execution tolerances and consequently improve the execution efficiency.

In the first phase of the experimental program (Fig. 4.4), a feasibility study was performed during the execution process and it was evaluated that Φ32 mm bolt holes would be appropriate to capture the deviations resulting from geometrical and dimensional imperfections. This led to a hole clearance of 12 mm which is much larger than the typical hole clearance of 1–3 mm for M20 bolts according to the

Fig. 4.4 Overview of experimental set-up [9, 13]

EN1993 [21] provisions. However, the injection of the epoxy resin in the bolt-to-hole clearance prevented the initial slip of the external bolt [20]. Six four-point bending experiments were performed with different shear connector arrangements. These different shear connector arrangements concluded the fact that concentrating the shear connectors near the supports reduced the deflection of the composite beam by 6% and thus led to increased composite interaction [20]. Regarding the inelastic tests, the experiment was terminated when the nominal resistance of the hydraulic actuators was reached (F = 550 kN) but up to that point the failure mechanism was yielding of the steel beam and plastic deformation of the shear connectors with no concrete damage.

The same injected shear connector was tested in a cast in-situ steel–concrete composite slab with profiled sheeting [10]. The composite slab in this case was tested in two life cycles under total working loads up to 200kN in a four-point bending set-up. During the first cycle, different arrangements of the shear connectors were tested within the serviceability limits. After the first cycle of experiments, the composite slab was cut through the timber joists which provided the cut edge of the slab. After the first cycle of testing the slab was demounted, reassembled, and tested again in a second life cycle. It was reported that the effective bending stiffness of the beam in the elastic area was decreased in the second cycle by an average of 10.5% [10]. This observation was attributed to the decrease in the bending stiffness of the steel section, of the concrete slab, and the initial stiffness of the shear connector. Regarding the bending stiffness of the slab, the possible decrease was inferred from the change in the longitudinal stress distribution across the slab width after cutting the composite slab. With respect to the decrease of the initial stiffness of the shear connectors, it was assumed due to possible damage which could have occurred during re-assembly.

4.4 Conclusions

This paper presents an overview of the most recent developments regarding the technical strategies and design recommendations for the reuse of reclaimed steel elements and steel–concrete composite structural components. It also discusses the types and properties of connections between these components which allow deconstruction and reuse. The main conclusions are summarized below:

- The idea of reusing composite structural elements is highly supported by guidelines and recommendations addressing the reusability of buildings, even if it is still at the initial stage of application in practice.
- The three main phases for the reuse of a structural component according to European guidelines [14] include (a) the pre-deconstruction audit and assessment for reuse, (b) sampling (in terms of grouping) and certification of structural components, and (c) design for reuse.

- Demountable connectors are the essential component that contributes to the demountability of a steel–concrete composite structural system. The injected bolted shear demountable connectors allow for oversized holes which can account for the fabrication and execution tolerances.
- The feasibility of assembly and disassembly of demountable prefabricated steel–concrete composite floor systems with the injected bolted shear connectors was confirmed through large-scale experiments.
- Beam tests with cast in-situ steel–concrete composite slab with profiled sheeting demonstrated a small decrease in the effective bending stiffness of the composite beam in the elastic area when tested in a second life cycle. It was also demonstrated that the system can be relatively easily demounted after the first life cycle and placed back to its original location for a second life cycle in laboratory conditions. However, more experiments will contribute to a better understanding of the second life cycle performance of the composite slabs.

References

1. Brambilla G, Lavagna M, Vasdravellis G, Castiglioni CA (2019) Environmental benefits arising from demountable steel-concrete composite floor systems in buildings. Resour Conserv Recycl 141(1):133–142. https://doi.org/10.1016/j.resconrec.2018.10.014
2. Organisation for Economic Co-operation and Development (2019) Global material resources outlook to 2060: economic drivers and environmental consequences. OECD Publishing
3. Cramer J (2015) Circulaire economie: van visie naar realisatie. Utrecht Sustainability Institute
4. Danatzko J, Sezen H (2011) Sustainable structural design methodologies. Pract Period Struct Design Constr 16(4):186
5. Liu X, Bradford MA, Lee MSS (2015) Behavior of high-strength friction-grip bolted shear connectors in sustainable composite beams. J Struct Eng 141(6):04014149
6. Ataei A, Bradford MA, Liu X (2016) Experimental study of composite beams having a precast geopolymer concrete slab and deconstructable bolted shear connectors. Eng Struct 114(1):1–13
7. Kwon G, Engelhardt MD, Klingner RE (2010) Behavior of postinstalled shear connectors under static and fatigue loading. J Constr Steel Res 66(4):532–541
8. Pavlovic M, Markovic Z, Veljkovic M, Budevac D (2013) Bolted shear connectors versus headed studs behaviour in push-out tests. J Constr Steel Res 88:134
9. Nijgh M.P, Gîrbacea I.A., and Veljkovic M.: Optimization of a composite (steel-concrete) floor system for fast execution and easy demolition, Proceedings of the Scientific Conference on Planning, Design, Construction and Building Renewal (iNDiS 2018), 45, (2018).
10. Gritsenko A (2018) Towards a demountable composite slab floor system. Master's thesis, Delft University of Technology
11. Odenbreit C, Kozma A (2019) Dismountable flooring systems for multiple use. In: IOP conference series: earth and environmental science, vol 225. IOP Publishing, p 012028
12. ECCS (1994) European recommendations for bolted connections with injection bolts, vol 79. ECCS
13. Kavoura F, Veljkovic M (2022) Technical practices of re-usable steel-concrete composite structural systems. In: 3rd coordinating engineering for sustainability and resilience CESARE 2022. Jordan University of Science and Technology
14. PROGRESS: Provisions for Greater Reuse of Steel Structures (2020) Grant agreement no: 747847, Research fund for coal and steel. European Commission

15. Brown D, Pimentel R, Sansom M (2019) Structural steel reuse. Steel Construction Institute SCI
16. Terwel MRC, Korthagen RC (2021) Voorbij de pioniersfase. Bouwen met Staal 54
17. Nationale Bruggenbank (2023) Nationale bruggenbank. https://www.nationalebruggenbank.nl/. Accessed 10 Feb 2023
18. Platform CB'23 (2018) Over platform cb'23. https://platformcb23.nl. Accessed 15 Feb 2023
19. van Lookeren Campagne F (2022) Efficiently including reclaimed steel elements in a truss bridge design: by performing a stock-constrained shape and topology optimization. MSc thesis, Delft University of Technology
20. Nijgh MP (2021) A multi-scale approach towards reusable steel-concrete composite floor systems. PhD thesis, Delft University of Technology
21. EN 1993-1-8 (2005) Eurocode 3: design of steel structures—part 1–8: design of joints
22. Research Fund for Coal and Steel (RFCS): Reuse and demountability using steel structures and the circular economy. REDUCE, project number RFCS-02-2015