

TECHNICAL PRACTICES OF RE-USABLE STEEL-CONCRETE COMPOSITE STRUCTURAL SYSTEMS

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Abstract. *The demountable and reusable steel-concrete composite structures contribute immensely at the sustainable development in construction. The main technical practice which allows for demountability and reusability is the use of demountable shear connectors in their floor systems. These demountable shear connectors can satisfy the need for composite interaction of the steel-concrete composite floor system during its service life and in parallel the need for large nominal hole clearances during execution through oversized holes in the beam flange. These oversized holes facilitate the (dis)assembly process of the floor system. The developed demountable shear connector consists of (i) a bolt and coupler embedded in the floor, (ii) an external injection bolt through the beam flange and (iii) an injection material in the bolt-hole clearance. This injection material is a two-component epoxy resin and its benefits are focused on the increase of the stiffness and strength of the connection and the decrease of its creep deformation when compared to injected connections with conventional epoxy resin. This paper is focused on experimental of the most recent technical innovations for demountable shear connectors studied at the Delft University of Technology along with their benefits on material, connection and structural application levels.*

1 INTRODUCTION

A sustainable design methodology needs to aim on the material-efficient use and on the production of layouts that allow a whole or partial structural component to be reused and achieve longer structural life spans [1]. Regarding efficient material use, the research is directed towards the use of multi-material structural components because of their advantages. Current developments of the steel-concrete composite structures underline their advantages in respect to their speed of construction, decrease of the floor weight and consequently the self-weight of the structure and achieving larger floor span when compared with other type of structural systems (e.g. reinforced concrete) [2]. According to the common constructional method of the steel-concrete composite floor systems, the steel beams are connected with welded headed studs which are encased within the concrete slab in order to achieve the necessary shear connection. This construction method leads to a non-demountable structure which require demolition of the structure in the end of its life (see Figure 1a). For this reason, the benefits of demountable steel-concrete shear connectors in terms of their contribution on demountability and reusability of structural systems have been studied over the last years along with their environmental benefits [3].

The structural concept of the demountable shear connectors contributes to the sustainable development of the built environment. It addresses the need for composite interaction while in parallel enables the non-destructive separation of the steel beam and the concrete floor as shown in Figure 1b. Variety of connectors have been investigated in the literature which include friction-based shear connectors [4-7], bolted headed studs with embedded nuts [8-10] and embedded coupler shear connectors [6, 11-15]. The former type of demountable shear connectors is discussed in this paper with the use of injection external bolts. The injection bolts are bolts filled with a two-component epoxy resin from their head and are commonly used in shear connections where slip should be avoided, as an alternative for fitted [16] or pretension bolts. The details of this shear connector are shown in Figure 2. This paper presents the details and experiments on these connections on component and structural system level performed at the Delft University of Technology.

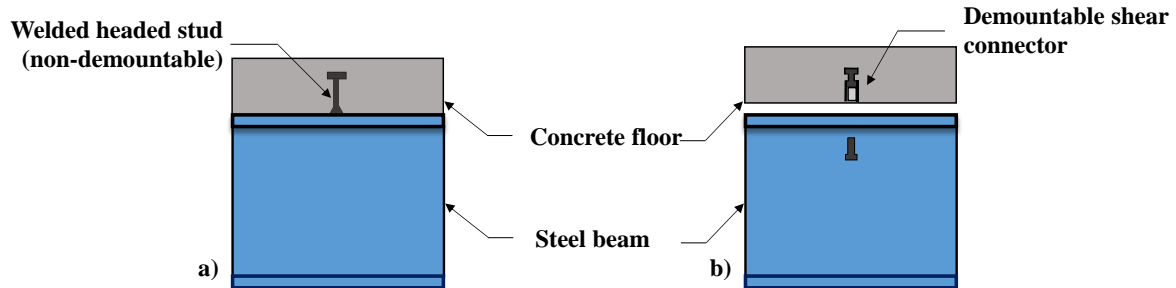


Figure 1. The technical solution of the replacement of the (a) welded headed studs with (b) demountable shear connectors in order to enable the reuse of the steel-concrete composite floors.

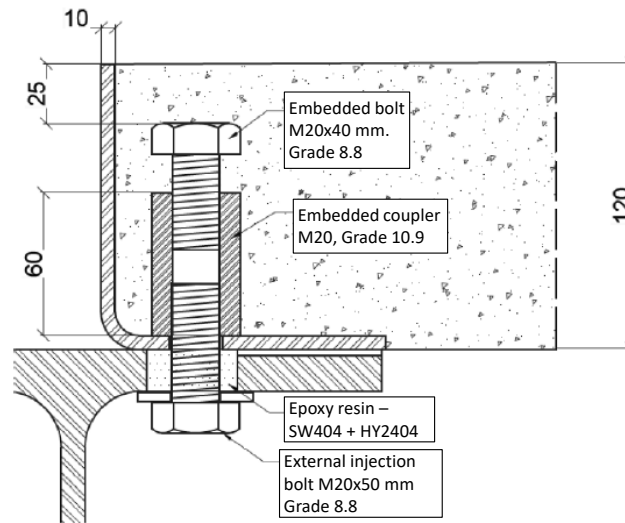


Figure 2. Demountable shear connector for composite floor systems [15].

2 DEMOUNTABLE INJECTED BOLTED SHEAR CONNECTORS

2.1 Materials for the injected bolted connections

Two-component epoxy resins are commonly used for the injection bolts (see Figure 3a) application and they should comply with the specifications of EN 1090-2 [17] regarding their viscosity, their thixotropic behavior, and their pot time. The two-component epoxy resin used for the application of the demountable shear connector under consideration is the RenGel SW 404 in combination with the hardening agent Ren HY 2404 [19]. The same resin containing spherical steel particles (see Figure 2b) which is called Steel Reinforced Resin (SRR), has been tested under compressive loads and its mechanical properties have been compared with the conventional one [20]. Under unconfined conditions the RenGel SW 404/2404 showed a highly ductile behavior in comparison with the reinforced one and a higher compressive strength [20]. However, on connection level where natural confinement is provided by the bolt hole, the SRR showed to benefit the connection. Specifically, tests on double lap shear connections with injected SRR in large oversized holes (bolt diameter + 12 mm) indicated that the connection realized an increase in the instantaneous stiffness (by 71%) and a decrease in the time-dependent deformations (by 38%) when compared

with the conventional resin-injected specimens [18].

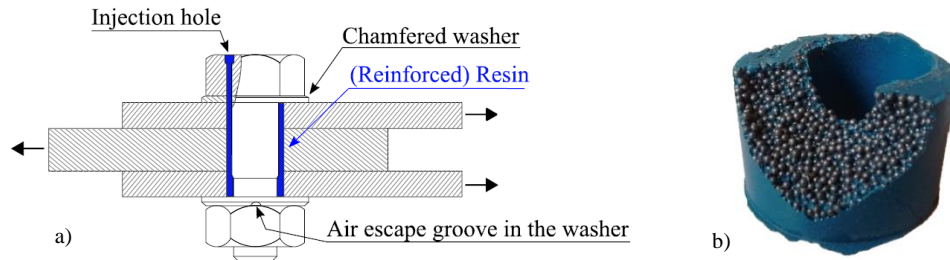


Figure 3. Cross-section of injection bolt [21], cross-section of SRR [18]

2.2 Mechanical behavior of injected bolted shear connector with a coupler system

The injected bolted shear connector with a coupler system consists of a coupler welded on a steel L-shaped profile on top of the steel beam in which two bolts are connected (see Figure 2). The L-shaped profile is introduced to prevent damage to the bottom edges of the prefabricated concrete elements during the reuse [22]. The removable (external) bolt is placed from below the steel beam flange and the other bolt is embedded in the slab. The removable bolt has lower strength than the coupler, so damage related to the overloading of the shear connector accumulates in the removable bolt rather than in the embedded coupler. In this manner, in a subsequent life cycle the removable bolt can be replaced and the concrete deck can be re-used [15]. It should be mentioned that the steel section includes oversized holes which proved to be very beneficial in terms of their execution efficiency, demountability, and reusability of the steel-concrete composite floor systems [11].

The mechanical behavior of injected bolted shear connectors with a coupler system (see Figure 2) has been studied experimentally through push-out experiments [22] and the average results are shown in Table 1. Two sets of experiments were carried out; in the first set the bolts were injected with conventional epoxy resin and in the second one they were injected with SRR. From the experimental results it was found that the average resistance P_u was approximately the same for the epoxy resin ($P_u=115.6$ kN) and the SRR ($P_u=118.2$ kN) injected shear connectors specimens. The governing failure mechanism was shear failure of the injection bolt. The secant stiffness at 70% of P_u of the steel-reinforced resin-injected specimens was almost double compared to that of the resin-injected specimens (98 kN/mm and 46.3 kN/mm respectively). In both cases the shear connectors demonstrated a ductile behaviour according to EN 1994-1-1[23] provisions.

Injectant	P_u (kN)	Secant stiffness at $0.7P_u$ (kN/mm)	Initial stiffness (kN/mm)
Resin	115.6	46.3	95.5
SRR	118.2	98.0	171.6

Table 1: Average push-out test results with conventional epoxy resin and with SRR injectant in steel-concrete structures [22].

2.3 Four-point bending experiments on demountable steel-concrete composite beams

Experiments on prefabricated composite floor systems which were designed to replicate a typical car park building were performed in order to evaluate the feasibility and the performance of this demountable and reusable structural system [15] at Delft University of Technology. The design consisted of three simply supported web-tapered steel beams and four prefabricated concrete floor elements. The physical assembly in the laboratory environment can be

seen in Figure 4. The injected bolted shear connectors with a coupler system presented in section 2.2 were applied in these beam tests. The embedded and injection bolts were M20 grade 8.8 while the coupler was M20 and grade 10.9. The injectant epoxy was the RenGel SW 404/2404, presented in section 2.1. Deflection measurements were taken at the midspan of the beam and at the locations of the loading frames (at 4.05m from each support).

During the execution process a feasibility study was performed and it was evaluated that Ø32 mm bolt holes would be appropriate to capture the deviations resulting from geometrical and dimensional imperfections (e.g. the scatter in the position of the shear connectors in the formwork). 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. However, the injection of the epoxy resin in the bolt to hole clearance prevented the initial slip of the external bolt [22].

Six four-point experiments with different shear connector arrangements were performed for the evaluation of the structural response of the system during its service life. These different shear connector arrangements included uniform shear connector spacing throughout the beam or concentrated spacing near the supports. It was found that concentrating the shear connectors near the supports (see Figure 5a) reduced the deflection by 6% and thus led to increased composite interaction [22]. The system with the same configuration of shear connectors was tested in the inelastic area. The experiments was terminated when the nominal resistance of the hydraulic actuators was reached ($F = 550$ kN). Up to that point the failure mechanism was yielding of the steel beam and plastic deformation of the shear connectors. No concrete damage was observed.



Figure 4. Overview of experimental set-up [22]

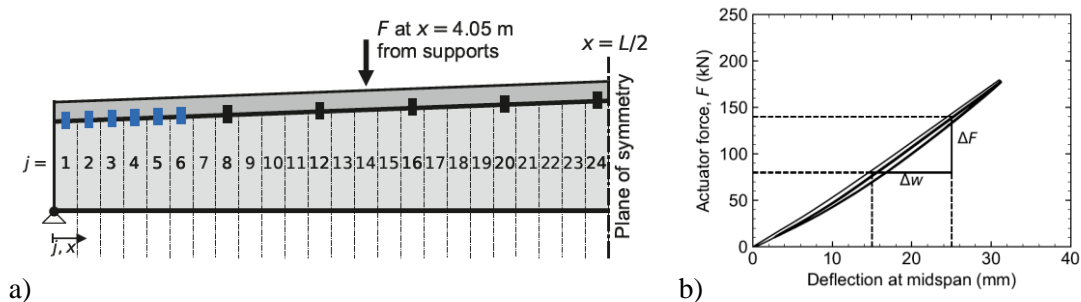


Figure 5. a) Shear connector arrangement near the supports (blue-colored bar indicates a pair of shear connectors set-up), b) corresponding force-displacement curve [22]

The same injected shear connector was tested in cast in-situ steel-concrete composite slab with profiled sheeting [24] (see Figure 6a) at Delft University of Technology. The detail of the demountable shear connector and the beam test setup are presented in Figure 6. In this case the composite slab was tested in two life cycles under total working loads up to 200kN in a 4-point bending set-up (see Figure 6b). 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, demounted, re-assembled and tested again in a second life cycle. It was observed that the effective bending stiffness of the beam in the elastic area was decreased in the second cycle on an average of 10.5%. This observation was attributed to the decrease of the bending stiffness of the steel section, of the concrete slab and the initial stiffness of the shear connector. Specifically, regarding the bending stiffness of the slab, possible decrease was inferred from the change in the longitudinal stress distribution across the slab width after cutting. Regarding the decrease of the initial stiffness of the shear connectors, it was assumed from possible damages which could had been occurred during re-assembly. Furthermore, the averaged effective shear stiffness based on the end slip demonstrated a decrease in the second life cycle test by 9.2 % on an average (depending on the arrangement of the shear connectors on the beam). Further recommendations for a more feasible and easier demounting and re-assembling of the cast in-situ steel-concrete composite slabs are proposed in this research [24].

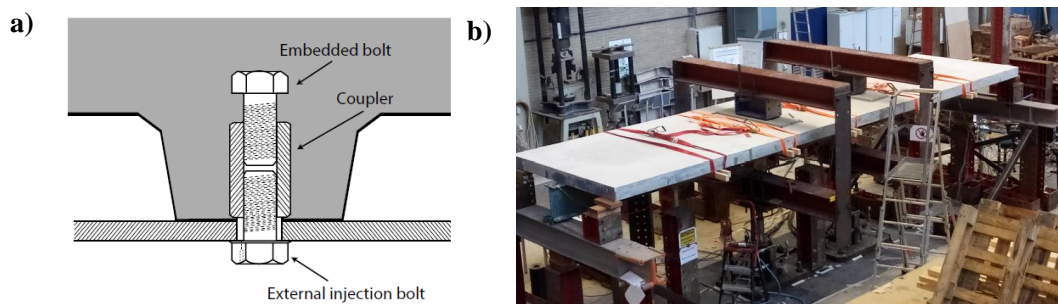


Figure 6. (a) Injected demountable shear connector on a composite slab, (b) composite floor test physical assembly [24]

3 CONCLUSIONS

This paper presents an overview of the most recent technical innovations for demountable steel-concrete composite systems studied at the Delft University of Technology. When it comes to the demountability and reusability of these composite structures, the proposed demountable shear connectors was proven to be a successful option. The main conclusions of this paper are summarized below:

- The epoxy resin on the injected bolted shear connectors acts as a load-bearing element and its resistance is higher than its uniaxial compression strength due to the natural confinement provided by the bolt hole.
- A novel epoxy resin containing spherical steel particles (SRR), has showed to benefit the injected bolted shear connection substantially by increasing its instantaneous stiffness and decreasing its time-dependent deformations when compared with the conventional resin-injected connections.
- The injected bolted shear connectors allow for oversized holes which can account for the fabrication and execution tolerances and consequently improve the execution efficiency of demountable composite system which eventually leads to more sustainable structures.
- The mechanical properties of the injected bolted shear connector resulted from push-out experiments showed that the average resistance P_u was approximately the same for the epoxy resin and the SRR injected shear connectors specimens. The secant stiffness at 70% of P_u of the steel-reinforced resin-injected specimens was almost double compared to that of the resin-injected specimens and in both cases the shear connectors demonstrated a ductile behavior.
- Large-scale experiments on prefabricated steel-concrete composite floor systems with the injected bolted shear connectors evaluated the feasibility of assembly and disassembly of these systems. It was found



that concentrating the shear connectors near the supports reduced the deflection at midspan by 6% and thus led to increased composite interaction (when tested under service loads). The failure mechanism was yielding of the steel beam and plastic deformation of the shear connectors.

- Beam tests with cast in-situ steel-concrete composite slab with profiled sheeting demonstrated the performance of the system in two life cycles under service loads. A small decrease of the effective bending stiffness of the beam in the elastic area was observed. It was also demonstrated that the system can be relatively easy demounted after first life cycle and placed back to its original location for a second life cycle in laboratory conditions.

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