Demountable construction for sustainable buildings

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DEMOUNTABLE CONSTRUCTION FOR SUSTAINABLE BUILDINGS

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Abstract

Year after year worldwide resources are becoming scarce. In the context of general reduction of resources it is necessary to save the used energy and to keep the spent resources in the material cycle. The fact of high material and energy consumption in the building sector leads to develop new method of constructions that have a sustainable use of natural resources. Besides the need to reduce CO_2 emission, the reduction of the use of mineral products needs a major course of action in Europe.

Several research works have been investigated about walls made of units and mounted with unbounded prestressing. Extending the same construction principle of the walls to the slabs will reduce the diversity of building materials.

The contribution is based on the project REMOMAB which examined different principles for fully recyclable massive modular designs. This project focuses mainly on the structural considerations. As an approach for recyclable design of structures can be seen for example the use of walls made of separate units mounted by unbounded prestressing. Therefore it is possible to disassemble mounted structural elements in case of reaching its lifetime.

1. INTRODUCTION

One of the greatest economic, social and ecological challenges of our time is to ensure an efficient consumption of natural resources in order to preserve the natural environment. This aim is increasingly gaining prominence on the national and international political agendas. Efforts in Europe have led to the drawing up in 2011 of a Road Map for a "Resource Efficient Europe". The German government has also made progress in meeting these challenges by setting up its own resource efficiency programme, "ProgRess". Here the main aim is to reduce the consumption of natural resources, thereby protecting against environmental damage and pollution while maintaining living standards and potentials for further development. One important aspect of resource efficiency is to expand the opportunities for the recycling of materials.

An exceptional importance is thereby attached to the building stock. It is one of the most important energy consuming sectors, binds an enormous economic prosperity and represents one of the greatest anthropogenic material stockpiles [1]. Buildings consume enormous sets of resources at their construction and release them at the end of their life time again [2]. The exploitation of this material stockpile by reuse and reutilization – so-called Urban Mining [3] – can represent a worthwhile step in the direction of the resource conservation. However, reclaimed demolition materials qualitatively are not comparable with the raw materials used at the beginning. The main reason for that is the use of material compounds, which complicates a separation of the ingredients/raw materials or completely inhibits in the worst case.

Across Europe, both in existing buildings and in new buildings a number of material combinations can be found. Commonly these materials are bounded together, which is an important argument for the level of reuse. Under current legislation, a part of the materials used in the past in Europe is hazardous waste and can only be disposed of with increased energy and cost [4]. The "Flagship initiative under the Europe 2020 Strategy" [5], which is similar to „Sustainable Materials Management" of the OECD, formulated clearly requirements for the character of material cycles. The aim of the EU strategy is to minimize exhausting hazardous materials at retrofitting or removal of buildings as well as their harmless, cost-effective and energy-saving disposal by using specific separation. It is expected that this shift in perspective will have a future effect on the building and construction industry, too.

1.2 Problem statement

In Germany, the mineral resources flow almost exclusively into the construction sector, and therein nearly fifty-fifty into buildings and infrastructures [1]. In addition, the building process causes currently approximately 52% that is the largest part of total waste [6]. For the implementation of EU resources strategy [5] into German policy, the use of raw materials in housing should reduce to 2025 by 50% and in addition the amount of waste should imitate.

In contrast, currently the majority of the material flows of building constructions is characterized by linear, open processes [7]. Therefore, among other things, almost all structural connections, especially those at the solid construction, are based on processes where different materials are intimately, firmly and inextricably connected: concrete – reinforcing steel – concrete, plaster – thermo skin, concrete – plaster etc.

Thus, difficult separation takes additional time, effort and energy. Therefore, the recycling process for mineral products currently is situated at a low level, in comparison, for example, with the automotive industry. The result of RC-crushing is concrete rubble and scrap of reinforcing steel. Recycled aggregates have in most cases a very heterogeneous composition of substances. For this reason it is mainly supplied to secondarily reuse opportunities or landfilling. Thus, valuable mineral resources and construction materials once produced are no longer available [8].

However, the finite nature of resources requires a change in thinking, even in massive construction. At the end of the use of a structure, the components once produced, should be possible to disassemble and sorted by a simple separation process. The building material – or an entire device – can thereby reused. Here, areas such as electrical, mechanical, or automotive industry serve as a model for future design and construction strategies in building [9] [10].

2. DISMOUNTABLE CONSTRUCTIONS

2.1 Aim

The requirement for recyclability or reusability of concrete structures results in a contradiction between durability and dismountability, which forms a need for optimisation. Therefore, in this paper exclusively potential technical solutions are presented and discussed. Additionally, possible further innovations are given in the outlook.

The construction procedure needs adjustment for obtaining dismountability. Monolithic connections have to be minimized. Instead, contact interfaces must be used for links. Such contacts are e.g. supports of beams or stacking of blocks without additional cohesive interface material. The advantage of such connections is the later unmixed separation of large parts of the construction.

Disadvantages are summarized as follows according to [11]:

- Because of the elimination of contact material enormous requirements to parallelism and flatness of the bearing surfaces of the blocks appear.
- Due to lack of bond strength any tensile, shear and bending strength is lacking without perpendicular load. To activate friction within joints a permanent load, a prestressing or an interlocking (nubby blocks) of corresponding components is necessary.

2.2 Prestressing of floor slabs made of blocks

In the case of bearing a bending moment by using blocks, it is necessary to superpose occurring tensile stress by a normal stress by applying a centric load. A significant bending moment exists. To reduce the resulting tensile stress in the flexural zone, a tendon would be needed to apply additional compression.

At the present case a full prestressing with unbonded cables, perpendicular to the contact joints seems to be suitable. Basically, the prestressing without bonding the tendon is situated in a borehole. The accessibility to the tendon must be given for retighten or replace the tendons. The corrosion protection of the prestressing elements is prepared by grease in combination with PE-coating

The larger the span, the higher the compressive design strength of the blocks is required. The procedure for engineering-design of the preload as well as the strength can be summarized as follows:

- determination of the relevant load
- calculation of the relevant bending moment
- determine the strain state
- identification of creep and losses due to slip
  - → full compensation of tensile stresses due to a central normal force, including creep and slip losses, thus no tensile stresses in the cross section exists
- verification of the stress in the compressive zone of the cross-section
- verification of the prestressing tensile force of the tendon
- decompression check

2.3 Numerical pre-analysis

A simple numerical model was used to get information about the practicability, size and span of preloaded slabs. Figure 1 shows the mode of failure due to a monotonic loading. Criterion for the fracture mode is the opening of the joints until the half of the cross section.

At a span of 3.0 meters, the maximum compressive stress at the block is 14 MPa. The ultimate span with a material strength of 20 MPa could be found with approximately 4.0 meters.

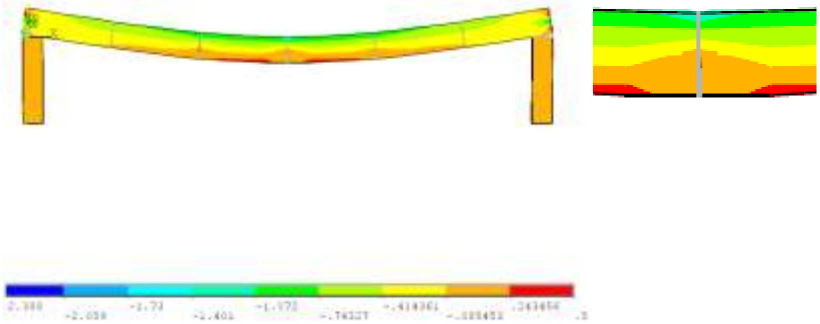

Figure 1: Deflection of a prestressed slab made of blocks; Detail

3 EXPERIMENTAL INVESTIGATION

3.1 Materials

Based on the developed demountable slab constructions, the suitability of the proposed structures has to be determined. For an efficient experiment the test for the bearing capacity takes place exclusively at prefabricated blocks (Figure 2) with a compressive strength of 26 MPa. Table 1 summarized the characteristic values of the used blocks.

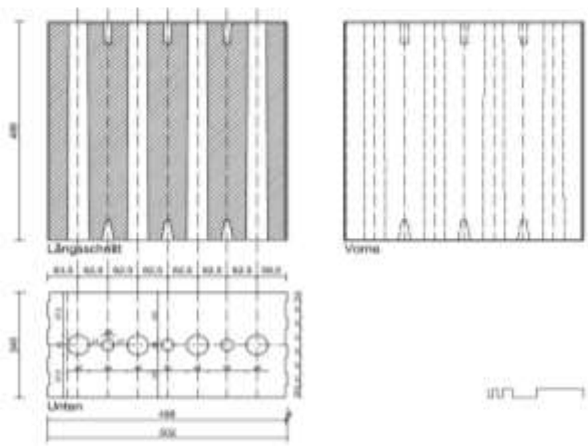

Figure 2: Used prefabricated blocks

A higher quality S 950/1050 tendon was used as prestressing steel, which was not further investigated because of the low load factor. A failure of the steel could be excluded in any case of use. The characteristic values of the tendon used for the investigations are given in Table 2.

Table 1: Parameters of used blocks

strength	26 MPa
density	1.8 t/m³
size	0.5 x 0.5 x 0.24 (m)

Table 2: Parameters of used tendon

strength	950MPa (S 950/1050)
diameter	26.5 mm
yield load	525 kN

3.2 Test setup

Figure 3 shows the geometry of the tested slabs. These contain 8 block rows in ½ shift-arrangement. The Rows 1, 3, 5 and 7 include two complete blocks in each case, the rows 2, 4, 6, and 8 are formed of one complete and two half blocks each. The total length of the slab is *l* = 4.003 m. Four tendons with a preload of 150 kN each realise the prestressing of the slab.

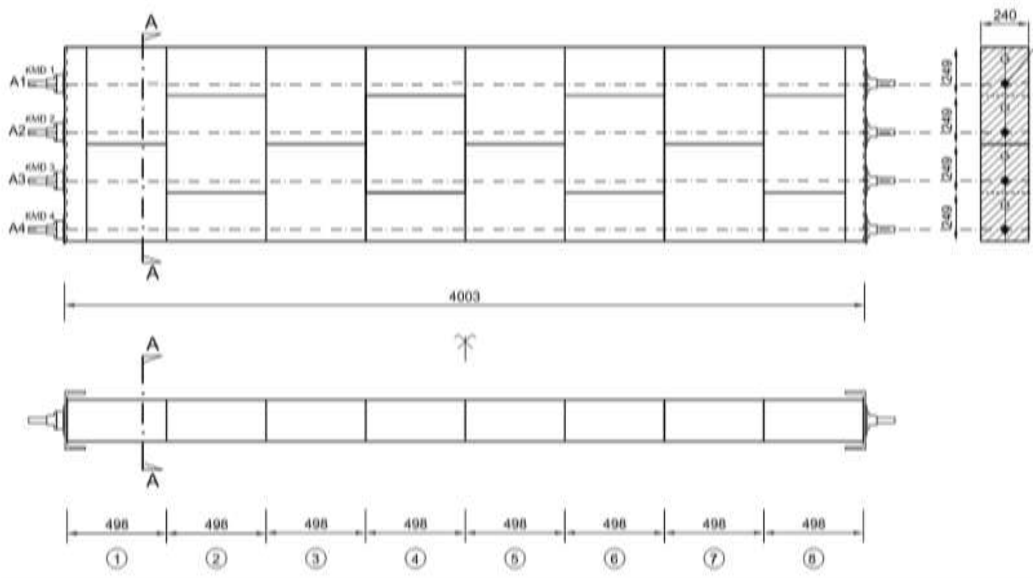

Figure 3: Shape and size of the test specimens

The aim of the bending tests on the prestressed slab was to determine the deformation behaviour under loading. Figure 4 shows the structure in the bending test with a quasi-surface load. The load was introduced into the slab via a whippletree system.

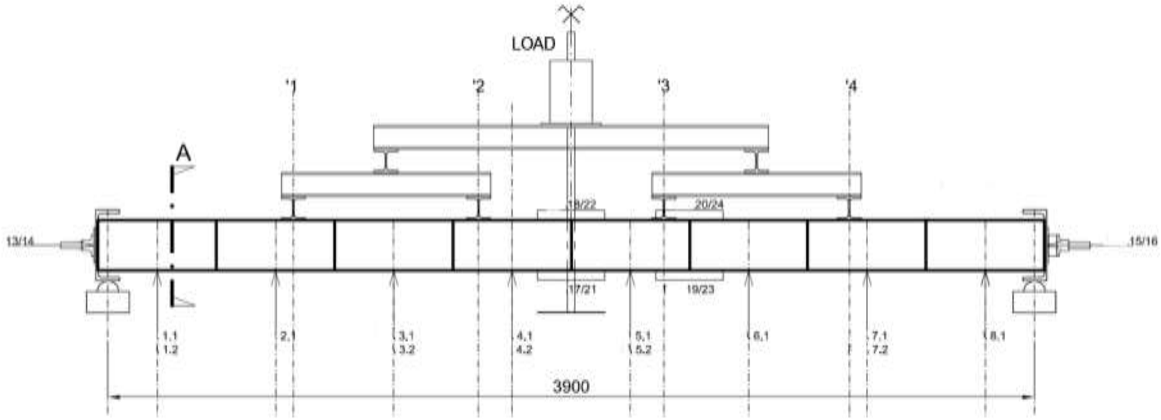

Figure 4: Test set-up for bending

Inductive displacement transducers (IDT) have been attached onto the slab to determine the deflection. In addition, IDT were arranged parallel to the bending lines on top and at the bottom to record compressions on the top and a possible gapping of the joints at the bottom. Furthermore, strain gauges were placed on top of the slab.

The focus of this study was on investigating the elastic and plastic deformations at increasing load.

Figure 5: Test set-up for bending

The load was continuously increased up to 100 kN, which corresponds to a surface load of 25 kPa. The corresponding force-displacement curve is shown in Figure 6.

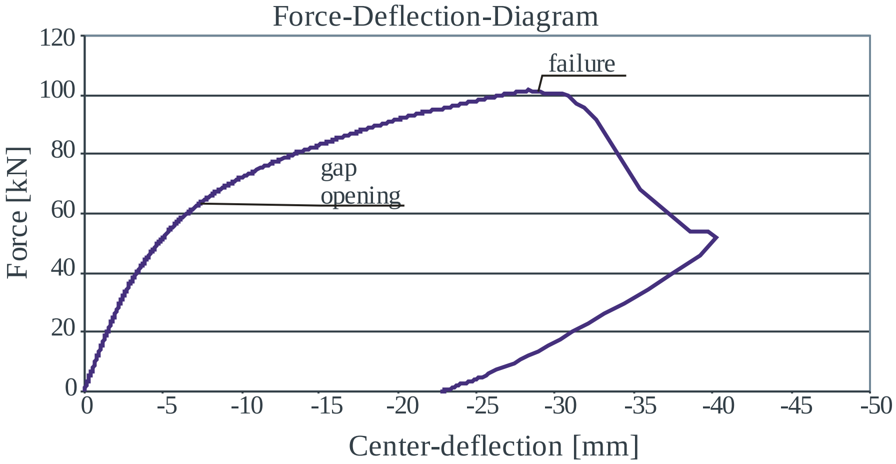

Figure 6: Test set-up for bending

From the experimental test results an ultimate limit surface load of 25 kPa in addition to the self-weight. Thus, the feasibility is demonstrated. The failure occurs at the top resulting of a compression failure of the block material. Nevertheless, the load bearing capacity of centric prestressed slabs is lower than of common concrete slabs, due to the position of the reinforcement inside the cross-section. The use of eccentric reinforcement of common concrete slabs gives obviously a higher bending performance.
However, against the background of resource conservation, the significant advantage of this slab is the possibility to disassemble it completely. Thus, the separated blocks can be entirely reused in new designed structures without loss of quantity and quality.

CONCLUSIONS AND OUTLOOK

The primary aim of demountable structures is to separate all components at the end of the economic life of a building without significant energy expenditure as well as to directly reuse or recycle as many components as possible. Fully demountable massive structures can be built with bondless assembled elements made of mineral material with a high precision. The usability of such structures could be verified by dry, centrally prestressed block elements. However, the load bearing capacity of the construction is not sufficiently yet, according to the current state of research to compete against common concrete structures. For a substantial progress in that case, further developments into the block material are essential.
Since the weak-point of the examined construction could be located in the compression zone of the cross section, the disadvantage of the comparatively low bending capacity is possible to increase by using materials of higher compressive strength, i.e. HPC with 100 MPa [12]. Furthermore, the use of FRC [13] or HPFRC [14], [15] leads to a higher capacity of contact stress, i.e. improved resistance against splitting tensile stress in the joint region, which has so far been proved for monolithic structures [16]. Due to this, HPFRC permits higher pre-stressing of the demountable construction. Experimental studies on this case are not completed yet. Further on, the bending capacity perpendicular to the plane may be improved by using an eccentric position of the prestressing tendons.

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