ON THE DISASSEMBLY AND REUSE OF CONCRETE STRUCTURES

ZUM ZERLEGEN UND WIEDERVERWENDEN VON BETON-KONSTRUKTIONEN

Hans W. Reinhardt

Institute of Construction Materials, University of Stuttgart

SUMMARY

The article gives a brief overview of the current status of demountable construction of concrete structures. After reviewing international literature, one gets the impression that interest in this type of construction has increased in the last five years, especially with the awareness that the supply of raw materials and fossil fuels are not infinite. It turns out that the research is primarily concerned with the connection of prefabricated parts, which are the core of this construction method. The National Bridge Bank of the Netherlands seems to be a good initiative to promote demountable structures.

ZUSAMMENFASSUNG

Der Beitrag gibt einen kurzen Überblick über den heutigen Stand des demontablen Bauens von Betonkonstruktionen. Bei der Durchsicht internationalen Schrifttums wird der Eindruck gewonnen, dass in den letzten fünf Jahren das Interesse an dieser Bauweise zugenommen hat, vor allem mit dem Bewusstsein, dass Rohstoffe und fossile Energie nicht unendlich sind. Dabei zeigt sich, dass sich die Forschung vor allem mit Verbindungen von Fertigteilen beschäftigt, die ja Kernstück dieser Bauweise sind. Die Nationale Brückenbank der Niederlande zeigt beispielhaft die Attraktivität demontablen Bauens.

1. INTRODUCTION AND MOTIVATION

Children build and construct with wooden blocks, with Märklin boxes, with Lego, with Playmobil, with Fischertechnik, with Matador all sorts of things, not just houses and bridges, but also vehicles, carousels, trains, fantasy structures, all items not intended to last but for the moment, which can be short, maybe midday, or longer, but never for "eternity". It would be too costly and impractical to keep everything. The individual parts are used, separated, then collected again and used again. It is exemplary environmentally friendly behavior. Thus, children learn to recycle right from the start. They also learn that this principle no longer works if the parts are glued or welded together.

As adults and professionals, we have forgotten this principle. There are of course reasons for this forgetfulness, for example that real structures are very durable and/or the owners are too unimaginative for frequent changes. As a rule, the individual parts are permanently connected to one another and cannot be separated without being destroyed. An exception are circus buildings, market stalls, grandstands, etc., which are referred to as "flying" buildings and are used "repeatedly and temporarily at different locations" [1].

On the other hand, there are many reasons why buildings should change during their long service life, and there are therefore reasons for structural adjustments. For example, the size of apartments depends on the number of people in the household. One forecast predicts that from 1991 to 2040, single-person households will quadruple, two-person households will remain about the same, and multi-person households will decrease.

Office buildings are subject to similar changes, for example when changing from open-plan offices to individual offices or when the need for floor space decreases due to many home offices.

Industrial buildings have to adapt to the rapidly changing work process. The number and size of road bridges depends on traffic development. The environment would benefit greatly if buildings and bridges were built to be resizable, dismountable and reusable. Steel and timber structures are predestined for this, concrete structures less so, but not excluded, as will be shown below.

2. DEMOUNTABLE CONCRETE STRUCTURES

2.1 Current situation

Concrete is a composite material consisting of a binder and aggregates. When the binder has reacted, concrete is durable for a long time. If you want to dismantle a concrete construction after a certain period of use, this can only be done by blasting, sawing or smashing, which always involves a certain degree of destruction. To prevent this, the construction must already have been designed and manufactured to be dismountable (demountable, decomposable).

A proposal was made almost 50 years ago that generated some research [2, 3, 4, 5, 6]. Around the same time, an agency of the Dutch Ministry of Construction published a catalog of concrete building systems for schools, office buildings, etc. that were demountable [7]. A symposium on the same topic was organized in Rotterdam in 1985 [8]. In 1990 a publication appeared on the use of demountable concrete structures in the areas of residential, office, industrial, bridge and energy construction [9].

2.2 Case study

How a prefabricated reinforced concrete building can be demounted is demonstrated with the following figures. The building was used for about 20 years. After that period of time, social problems arose which led to the conclusion that the twelve-story building was to demolish or lowered by seven stories. The second alternative was chosen. Fig. 1 shows the original building and Fig. 2 shows the building with 4 stories left.

Fig. 1: Original apartment building

Fig. 2: Building after removal of several stories

The demounting procedure is schematically demonstrated with Fig. 3. After cutting the tying reinforcement and removing the grout the prefabricated elements could be lifted.

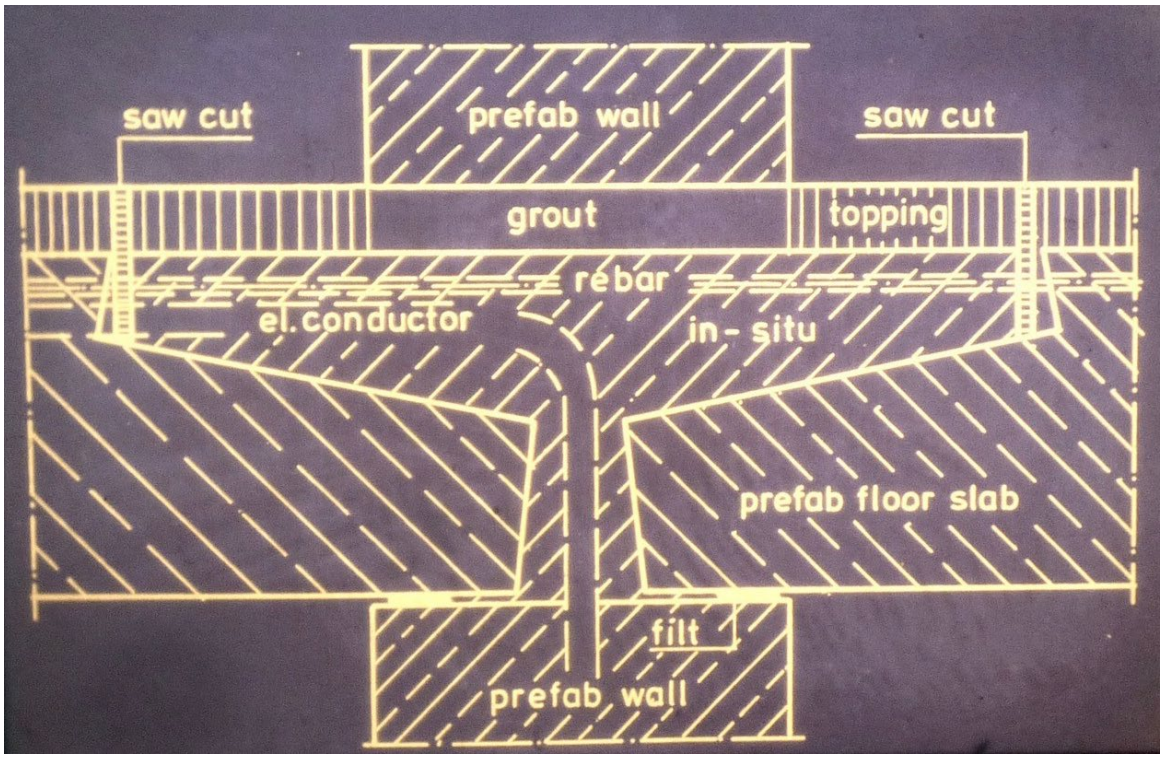

Fig. 3: Cross-section of prefabricated wall and slab indicating demounting procedure

Fig. 4: Reassembled stories at new location

They were not or only little damaged. On a new site the demounted elements could be reassembled. The new building which has only 3 stories is shown in Fig. 4.

The operation can be judged from various perspectives. The ecological gain was the reuse of material and the saving of energy. The production of new elements would have asked for cement, mixing and aggregates. From an economical point of view, it was more expensive. The project could only be carried out with financial support from the government. It has demonstrated that technically speaking, circulatory economy is feasible.

2.3 Current research

The awareness, that materials and energy are not infinite has triggered research on demountable and reusable structures. Current research is being conducted to update the state of knowledge. A few examples will be evaluated.

Concrete structures that can be dismantled typically consist of reinforced and/or prestressed precast concrete elements and detachable connections. As international literature shows, current research activities focus on such connections, mainly with regard to load-bearing capacity and rigidity.

The article [10] summarizes the knowledge of existing connections. It comes to the conclusion that these connections are not yet sufficient to be selected and used by structural engineers. The authors propose new types of connections between column and beam, column and slab, column and foundation, slab and slab, all made of steel elements. They can almost achieve the rigidity of a monolithic connection.

Yrjöla and Bujnak [11] report on a connection that has steel inserts at the four corners at the foot of a column that are not mortared in and can therefore be dismantled. The connection is a further development of an existing ETA-compliant screw connection from Peikko. Tests have shown that the new connection is slightly more flexible under horizontal loads than the existing one, but has sufficient load-bearing capacity. The authors propose to carry out further tests on horizontal displacement.

The article [12] deals with next-generation building systems (NGB = next-generation building), which should be environmentally friendly and therefore demountable and reusable. The proposed system consists of plates, T-beams and supports

that are clamped together with bolted connections. It is described as fully demountable, eco-friendly and reusable. The horizontal stiffness of a multi-story skeleton system is verified. This NGB system has the following characteristics: it is prefabricated, flexible and dismountable, so it has all the characteristic properties of demountability.

A simple connection of concrete elements consisting of steel plates and bolts is described in [13]. Relatively large displacements occurred under alternating loads. Further tests are necessary in order to obtain a component approval.

The authors of [14] first discuss the energy demand for erection and demolishing a precast structure and conclude that it would be favorable to design demountable ones which would save energy and material. They propose a new steel connection for combining a beam and a column. The heavy parts consist of a pen which slides in a groove in a plate. They can be separated by a reversed sliding motion. In principle, it is a shear key. Experiments have shown sufficient load bearing capacity.

Parking facilities are the topic of [15]. The design of the buildings is rather simple and suitable for demounting since they consist of columns, slabs, ramps and stairs. In this paper the columns have two corbels which act as support for slabs which are fixed by vertical bolts. Joints are filled with low-strength cement grout.

An example [19] of demountable dwelling houses should be mentioned. The houses are composed of concrete blocks which can be demounted and reused. Salama [20] gives a review on the current state of demountable buildings and presents a case-study of a detachable connection of façade elements.

The rather limited literature on demountable structures reports mainly on steel and timber structures and far less on concrete structures. However, since concrete prevails as construction material it would be worth paying more attention to it.

2.4 National bridge bank

The Netherlands is the promoter for reuse of bridges. As major clients of infrastructural projects, big cities have joined forces with the Netherlands directorate-general for public works and water management to establish the so-called National Bridge Bank where the owners of bridges can offer a bridge for sale [16]. This initiative was well received by practitioners so that the current catalog comprises all kinds of bridges, from pedestrian bridges to railroad bridges. Examples

of bridges are mentioned which are successfully reused on other locations [17, 18].

3. CLOSURE

This review gives an idea of international research activities in the field of demountable concrete construction. There are suggestions for non-positive connections, but also for positive ones. Some are operational with the necessary approvals, while others require further testing.

Since dismantling is a new territory for most architects and engineers, it takes time to be convinced, also in terms of costs and returns. It is well known that the introduction of new hypotheses and theories only succeeds when today's proponents no longer set the tone.

An encouraging example is the so-called national bridge bank provided by the Dutch, who already disassemble and reuse road bridges.

4. ACKNOWLEDGEMENT

The author would like to thank Dr. Aicher for a long lasting cooperation. Whether a tested particle board was needed or a piece of glulam or some parts of a trussed beam Dr. Aicher found some. It was an example for reuse of material on a structural level. He was also a reliable partner in several cooperative research projects. I wish him many more years in good health.

REFERENCES

[1] *Fliegende Bauten*, no standard available of DIN or EN, but approvals from the state test offices

[2] REINHARDT, H.W.: *Demontable Betongebäude?* Antrittsvorlesung Delft 1976

[3] STROBAND, J., KOLPA, J.J.: *Demountable construction, analysis of the behaviour of a 1:5 scale floor bay.* Part 1 Stevin-rapport 5-85-14, Part 2 Stevin-rapport 25-87-21, Part 3 Stevin-rapport 25-87-52, Technische Universiteit Delft, 1985-1987

[4] PAT, M.G.M.: *Demountable building construction ZEFE.* Stevin-rapport 3-83-19, Technische Universiteit Delft, 1983

[5] REINHARDT, H.-W.: *Demontabel bauen mit Beton*. Betonwerk + Fertigteil-Technik 51 (1985), Nr. 5, S. 300-305

[6] BOOGAARD, W.J. VAN DEN, REINHARDT, H.W.: *Demountable and remountable concrete structures for renovation.* Congress Report, 13th IABSE Congress, Helsinki, June 6-10, 1988, pp. 601-606

[7] RIJKSGEBOUWENDIENST: *Demountable construction systems of concrete.* Den Haag, 1996

[8] REINHARDT, H.W., BOUVY, J.J.B.J.J.: *Demountable concrete structures, A challenge for precast concrete.* Delft University Press 1985, 351 pp.

[9] *Demontabel bouwen*, CUR rapport 135, Gouda, April 1990

[10] FIGUEIRA, D., ASHOUR, A., YILDIRM, G., ALDEMIR, A., SAHMARAN, M.: *Demountable connections of reinforced concrete structures: Review and future developments.* Structures 24 (2021) 3028-3039

[11] YRJÖLA, J., BUJNAK, J.: *Shear tests on demountable column connections.* Structural Concrete 22 (2021) 2432-2442

[12] ANINTHANENI, P.K., DHAKAL, R.P.: *Demoutable precast concrete frame-building saystem for seismic regions: Conceptual development.* ASCE J. Archit. Eng. 23 (2017), 4: 04017024-1 bis 10

[13] CAI, G., XIONG, F., XU, Y., AMIR, S.L., YAN, L., YOSHIZAWA, M.: *A demountable connection for low-rise precast concrete structures with DfD for construction sustainability - A preliminary test under cyclic loads.* Sustainability 2019, 11(13), 3696, https://doi.org/10.3390/su11133696

[14] WITZANY, J., ZIGLER, R., POLÁK, A.: *Precast reinforced concrete demountable system of multi-storey buildings*. Insights and introduction in Structural Engineering, Mechanics and Computation, Zingoni (Ed.), Taylor &n Francis, London, 2016

[15] DHIR, R.K., DYER, T.D., HALLIDAY, J.E. (Eds.): *Sustainable Concrete Construction*: Proceedings of the International Conference, held at the University of Dundee, Scotland, UK, on 9-11 September 2002. London: Thomas Telford Publishing, 2002. (Challenges on Concrete Construction)

[16] National bridge bank, The Netherlands government, 2020

[17] VERGOOSSEN, R., JILISSEN, D., ECK, G.-J. VAN: *Hergebruik prefab T-liggers (1), Haalbaarheidsonderzoek en uitgangspunten SBIR consortium Liggers*. Cement 2022/6, p. 18-26

[18] Circulaire ontwerp-principes. Rijkstwaterstaat, Ministerie van Infrastructuur en Waterstaat, 2020

[19] JÄGER, W., YOUSSEF, H., METTKE, A., SCHMIDT, S., ARNOLD, V.: *Entwicklung und Anwendung von komplett demontablen Wohneinheiten aus ressourcenschonendem Beton.* Kurzbericht Forschungsvorhaben RCWE, Zukunft Bau, Dresden/ Cottbus 2020

[20] SALAMA, W.R.: *Design for disassembly as an alternative sustainable construction approach to life-cycle-design of concrete buildings*. Diss. Hannover, 2019