Zeitschrift: IABSE congress report = Rapport du congrès AIPC = IVBH Kongressbericht

Band: 13 (1988)

Artikel: Demountable and remountable concrete structures for renovation

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DOI: https://doi.org/10.5169/seals-13054

Demountable and Remountable Concrete Structures for Renovation

Rénovation des constructions en béton par démontage et remontage

Erneuerung von Betonbauwerken durch Demontage und Remontage

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SUMMARY
Demountable construction supports the flexible use of a structure, helps to save cost, material, and energy, and protects the environment from noise and dust due to demolishing. Theoretical and experimental studies show that demountable concrete structures are technically feasible. Practical cases demonstrate that demounting and remounting lead to economic results if some requirements are fulfilled.

RÉSUMÉ
La capacité d'une structure de pouvoir être démontée rend son utilisation plus flexible, et épargne de l'argent, des matériaux et de l'énergie et protège l'environnement du bruit et de la poussière pendant la démolition. Les études théoriques et expérimentales montrent que des structures démontables en béton sont réalisables. L'expérience pratique indique que le démontage et le remontage offrent des solutions économiques si quelques conditions sont remplies.

ZUSAMMENFASSUNG
Demontables Bauen unterstützt die flexible Nutzung von Konstruktionen, hilft mit, Kapital, Material und Energie zu sparen und schützt die Umwelt vor Lärm und Staub beim Abbruch. Theoretische und experimentelle Untersuchungen zeigen, daß demontable Betonkonstruktionen technisch möglich sind. Fälle aus der Praxis machen deutlich, daß Demontage und Remontage auch zu wirtschaftlichen Lösungen führen, wenn einige Voraussetzungen erfüllt sind.

1. INTRODUCTION AND MOTIVE

Structures are designed according to the requirements of size, shape, service load, production lines, thermal insulation, technical installations and many others. The requirements are defined by the actual owner who considers the technical possibilities, the economical and social boundary conditions, and his own experiences of today. All these aspects change with time. The longer a structure can fulfil the purpose, the better is the design.

However, here is a gap between the rapid changes of production methods in plants, of social environment, living style, and office equipment on the one side, and the long life of a concrete structure on the other side. If a structure does not allow a flexible use, i. e. the adjustment to new requirement, it will be demolished. This means waste of money, material and energy, impact on the environment by noise and waste.

All these aspects were the reason that the CUR (Centre for civil engineering research, codes and specifications in the Netherlands) has started a research committee entitled Demountable Construction. The committee used the following definition: "Demountable construction is a building method which uses structural connections which are such that the structural parts can be demounted with no or little destruction and are suited for reuse. By this it is aimed at energy and material saving, at reduced noise and dust production during demolishing, and at deminuition of the waste problem". The committee has tried to accomplish this challenging task by theoretical considerations and laboratory testing which resulted in a final report [1]. In the same time it happened that a multistory appartment house was partly demounted and remounted at a new site [2].

2. ACTIVITIES OF CUR COMMITTEE

2.1 Theoretical considerations and survey of demountable structures

Demountable structures are designed as prefabricated structures, the parts of which are assembled by structural connections. Depending on the function of the structures a few areas can be distinguished: housing, office buildings, plants, bridges, and power stations. Each area has some characteristics. According to a FIP-inquiry, most prefabricated appartment houses consist of panels which are placed perpendicular to the longitudinal axis and carry the slabs. The stability in longitudinal direction is secured by stair wells or elevator. This structural system does not allow much flexibility in use. However, renovation is possible by total demounting and remounting as will be shown later.

Usually, office buildings do not consist of transverse panels but of columns, beams, load bearing facades and sometimes a longitudinal wall. The horizontal stability is supplied by cores or shear walls. The load acting on the facade is transferred to the core by the slabs which must have a certain shear stiffness and shear capacity (diaphragm action). If the slabs consist of prefabricated elements, the joints transfer the load since a reinforced concrete topping layer would make demountability impossible. The question how to design a demountable slab appropriately, was answered by testing and some theoretical considerations (see Chapter 2.2).

Structures for production plants are very various and often tailored to the special purpose. There are some recent developments which make demountable construction attractive [3]:

- the life cycle of industrial processes becomes shorter and shorter which asks for adaptation
- structures are part of an infrastructure which may not be demolished
- social aspects ask for new arrangements within buildings
- the life time of installation and structure is out of phase
- a modern structure is an assembly, therefore the structure should be integrated into this assembly.

Demountable structures should be based on a module which is the same as for the technical installation.

There are examples of temporary bridges in cities which consist of single span girders connected by bolts or unbonded prestressing tendons. The bridges serve vehicle traffic or public transport. - Structures for power generation and storage are manyfold. Although not yet realized, it may be assumed that solar, wave, and wind power plants which consist of many similar parts are suited for prefabrication and demountability.

Generally speaking, prefabricated structures can be made demountable and remountable if the connections are designed in a proper way. In the most cases the following will apply:

- compressive supports: dry mounting on filt or other pads and positioning by pin
- tensile connection: by bolts, welded steel parts, or prestressing tendons
- bending connection: tensile connections according to force distribution
- shear connection: mortar joints between slabs with shear keys.

The safety and stability requirements of a demountable structure are the same as for conventional structures. There may be less redundancy since most parts are statically determined, but on the other hand, the path of the forces is quite clear and transparent. The connections should be detailed carefully and made as simple as possible so that human errors on the building site are reduced to a minimum.

2.2 Laboratory testing

The CUR committee decided to carry out tests on a 1 : 5 scale floor bay in order to know the stiffness and loading capacity under horizontal forces. This has to be known for the stability assessment of buildings consisting of columns, beams, and slabs.

Fig. 1 shows half of the loading configuration since some tests were performed under reversed loading. The slab was supported by beams on roller bearings while the horizontal force was transferred to end shear walls. The beams were connected in three different ways (see Fig. 2).

The main conclusions of the experiments which are described in detail in [4], are:

- the floor bay consists of two rigid parts which behave elastically until the centre point opens which depends on the mortar strength and the prestress in the tendon of the tensile zone. Thereafter rotation starts which is controlled by the elongation of the total tendon length, i. e. the deformation is concentrated in one joint which opens up widely.

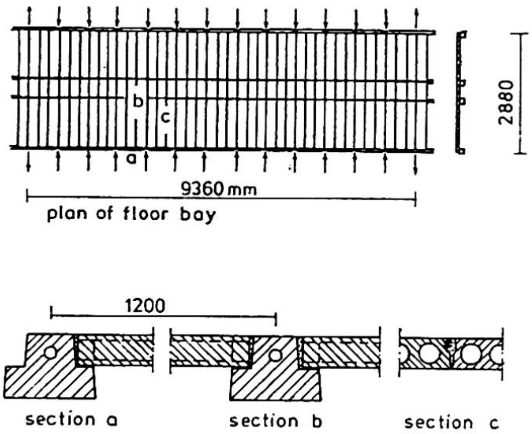

Fig. 1 1:5 scale model of a floor bay

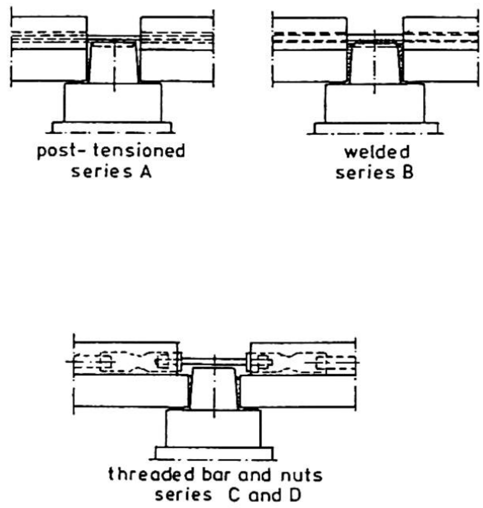

Fig. 2 Different connections between beams

- the floor bay can be schematized as an assembly of rigid parts, see Fig. 3.

  a) The stiffness of the tensile zone is given by the tendon which is fixed on the columns (Test series B).
  b) The stiffness of the tensile zone is the weighed average of the connection and the uncracked beam between two connections (Test C), see Fig. 4. The curvature of the bending line is then concentrated on the free part of the connections.

In both cases, the deflection of the floor can be calculated very simply by hand.

- the failure load is given by the shear capacity of the highliest stressed joint. The average ultimate shear stress was 0.13 MPa for a mortar with a splitting tensile strength of 0.3 MPa. Higher shear stresses can only develop if the edges of the prefabricated slabs have shear keys.
- the loading capacity depends strongly on the type of loading and the number of cycles. Alternating load is the most severe loading case, see Fig. 5.
- the deflection depends strongly on the number of cycles, see Fig. 6. Shear displacement is small if the joints do not open under service load. Connection of beams by prestressing or by stiff bolts can therefore be recommended.
- it is possible to design a demountable floor for horizontal forces without reinforced topping layer.

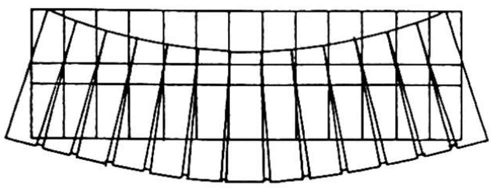

Fig. 3 Deflection of floor with unbonded tendon fixed at columns

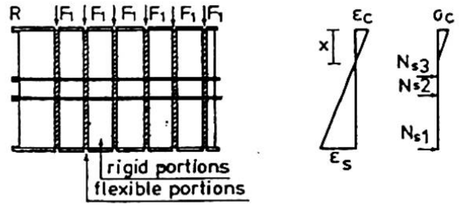

Fig. 4 Schematization of floor with connection between concrete beams

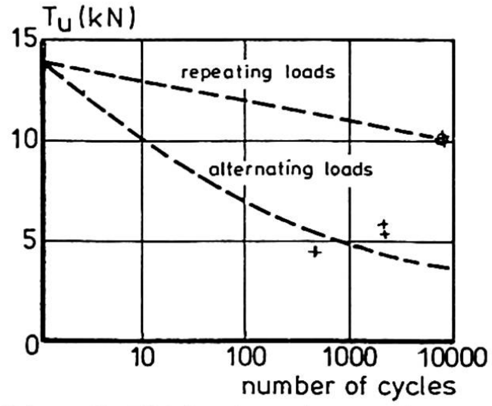

Fig. 5 Ultimate shear force vs. number of cycles

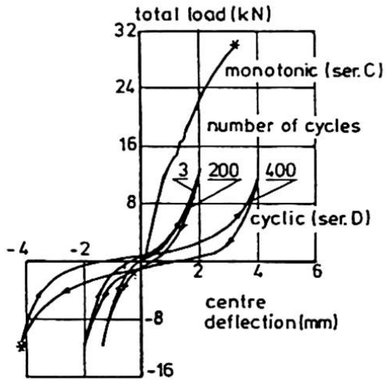

Fig. 6 Increase of deflection due to alternating load

2.3 Report

The committee prepares a report [1] which contains the information from an own literature survey, from an international symposium [5], from own theoretical and experimental finding. It deals with the design philosophy, safety considerations, the requirements and detailing of connections, and the fields of application. Examples of demounted and remounted buildings show that reuse is economic if the structure can be rebuilt at a nearby location in a similar fashion and if reuse was envisaged from the beginning. It seams unecomomic to demount a structure, store the parts and sell them on a second-hand market. The committee gives recommendations for demountable concrete structures.

3. EXAMPLE OF DEMOUNTED AND REUSED APPARTMENT HOUSE

In 1971/72, an appartment house was built with eleven stories. After only a few years, many families moved and the house became partly empty. Furthermore, garbage, vadalism and aggression grew more and more which caused the owner to find a solution for the social problem. After thorough consideration, the partly demounting and reuse of the building appeared to be the best solution. It was decided to demout seven stories, to transport them to a site in about two kilometers distance. So, 84 appartments are demounted and 114 new appartments are built in three and four story buildings.

This operation was only feasible, because two persons were available who were mainly responsible of the first construction in 1971, the design engineer and construction engineer. These two persons knew all about the system, the stability, and the sequence of construction. They were convinced that demounting should be possible although this was not intended in 1971.

Fig. 7 shows the essential detail of the panel system. Two slabs rest on filt on the wall, the space in-between is filled by concrete. Rebars protrude from the slabs joining each other. For demounting, the

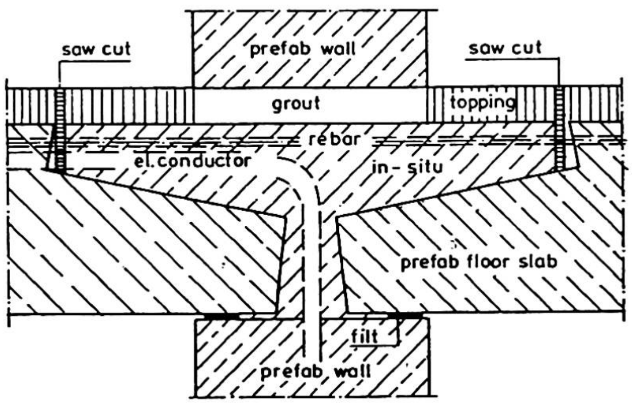

Fig. 7 Wall to floor joint of the Delta BMB system

rebars and the mortar are cut by sawing and removed. Then the slabs can be lifted and transported to the storage location.

It turned out that all structural elements could be removed quite easily. Only the stair wells which were cast in-situ have been demolished. Also the front panels with glazing and doors could be removed, transported and reused. The reerection went according to plan. Since the continuous rebars in the slab were cut, the stability of the building has been reevaluated. It turned out it could be ascertained by the slab with respect to vertical forces, but some extra measure was necessary for horizontal stability in longitudinal direction. The total project was successful in technical and economical sense. Whether other projects will follow depends on the specific circumstances.

4. CONCLUSIONS

The life time of a structure and the cycle of other processes are not in phase. This makes that a structure should be flexible in use or the structure has to be adjusted to new requirements. Furthermore, demolishing means waste of money, material, and energy which should be avoided.

Theoretical and experimental research on demountable concrete structures show that demountability is feasible if the philosophy of prefabrication is rigorously applied and if, furthermore, the connections are designed properly. It turns out that diaphragm action of a floor can be achieved without a reinforced concrete topping layer.

Practical cases demonstrate that demounting and remounting is technically feasible and ecomomic if some requirements are fulfilled.

5. ACKNOWLEDGEMENT

The work described is the result of the joint effort of the CUR-Committee Demountable Construction. The authors acknowledge gratefully the encouragement of the CUR and the fruitful co-operation of their colleagues in the committee.

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