MY INVOLVEMENT IN ENVIRONMENTAL ISSUES

MEIN ENGAGEMENT IN UMWELTFRAGEN

H.W. Reinhardt

Institute of Construction Materials (IWB), University of Stuttgart

SUMMARY

The paper shows several aspects of environment which have been touched by the author. The first refers to the demountable use and reuse of prefabricated concrete elements. This issue saves energy and building materials. The second activity refers to environmental pollution and a possible way of avoidance. The last aspect is the hint to cooperative research with partners from various disciplines and their specific contributions.

ZUSAMMENFASSUNG

Der Beitrag befasst sich mit verschiedenen Teilaspekten der Umwelt, zu denen der Autor beigetragen hat. Zum einen geht es um den Rückbau und die Wiederverwendung von Betonfertigteilen, was Energie und Rohstoffe sparen ließen. Der zweite Aspekt betrifft die Umweltverschmutzung und deren mögliche Einschränkung. Der letzte Gesichtspunkt ist die Zusammenarbeit bei Forschungsprojekten, womit sich eine bessere Nutzung der Forschungsmittel erzielen ließe.

1. INTRODUCTION

The environment has several aspects with relation to building and construction. One aspect concerns the resources of material since buildings and civil works need always construction materials like concrete, steel, timber and others. A second aspect concerns energy which is necessary for production of building materials, construction of buildings, heating and cooling of apartments, transportation and others. A third aspect relates to the pollution of air, water and soil due to industrial activities. All three impacts on environment impair the living condition of mankind, flora and fauna. The resources of material and fossil energy are finite which means that they should be used with caution and should be saved as much as possible in order that coming generation have enough of them. This was expressed in the declaration of Rio in 1992 which reads as follows faithfully “The environment has to be protected such that further generations can live as we do.” [1].

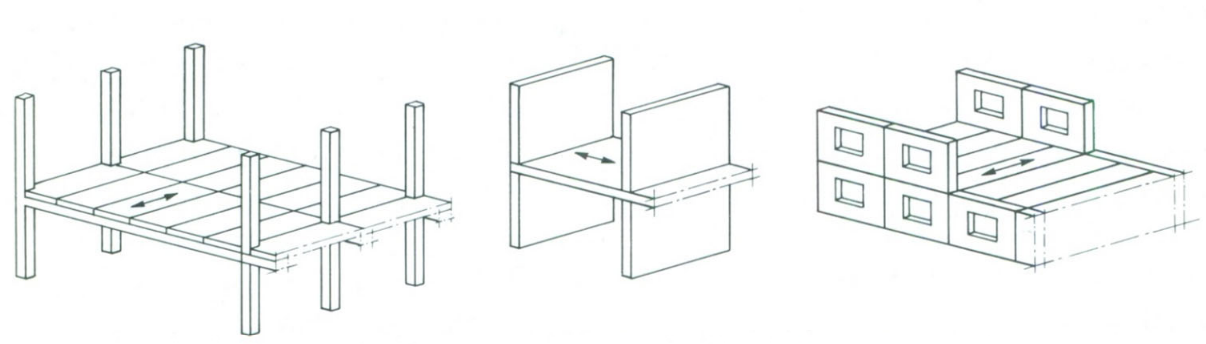
In the following, it will be shown that I was active in these fields. First, material and energy saving are touched, second, pollution of soil is important, third, saving of material by reuse and recycling are the topic.

2. DEMOUNTABLE CONSTRUCTION

The symposium “Adaptable architecture” organized by Frei Otto in 1974 [2] was an eye opener for me. Although the main emphasis was put on the architectural design of buildings, dwellings and settlements the questions of reuse of structural elements was also discussed. The flexible layout of dwellings, the industrial production of structural elements, the interchangeability of components and the reuse instead of demolition of building elements were stressed. It is well known that elements made of wood or steel were reused quite regularly in the past because it is easy to saw timber or to connect steel by bolts and rivets or welding. On the other hand, most structures of apartment buildings, offices, industrial plants are made of concrete. Therefore, the question arose why not designing concrete structures such that they can be demounted and reused.

There were attempts in the past which were not continued due to various reasons which were partly technical partly sociological. The modular systems did not satisfy esthetically and the occupants were not able to make use of the flexibility. The closed systems were no success so far.

A new approach was chosen at Delft University of Technology after my inaugural speech entitled “Demountable concrete structures?” [3]. Buildings can be divided in three main categories as the load bearing system is concerned: columns, beams and slabs, bearing interior walls, and bearing external walls, depicted in Fig. 1.



a) columns *b) load-bearing walls* *c) load-bearing facades*

Fig. 1: Main structural systems of buildings [4]

In Delft, the aim was to develop an open modular system consisting of prefabricated elements such as columns, beams and slabs. A schematic building is shown in Fig. 2 where the structural elements are columns, beams and slabs which are connected by ties.

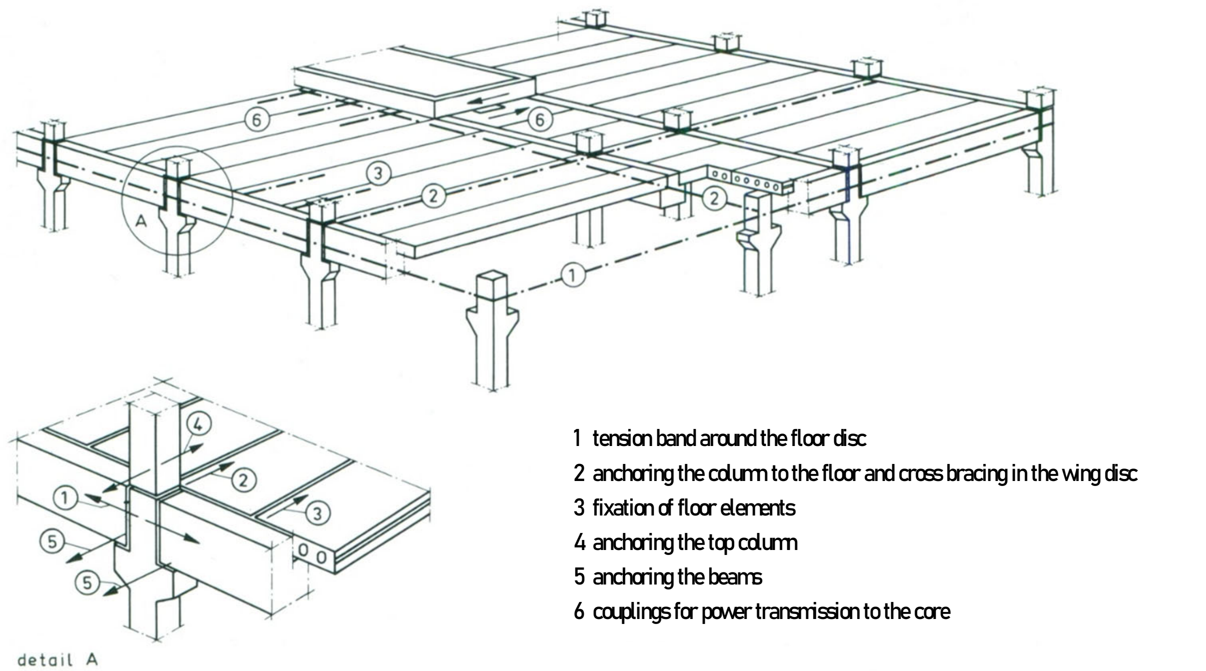


Fig. 2: Schematic building composed of prefabricated elements [4]

Normal and shear forces act in the joints between the elements. The joints should be accessible for demounting and realized by a low strength mortar. The overall stability should be secured by steel ties between the elements. The main focus of the experimental research was laid on the joints between the structural elements and their rigidity. An example is shown in Fig. 3.

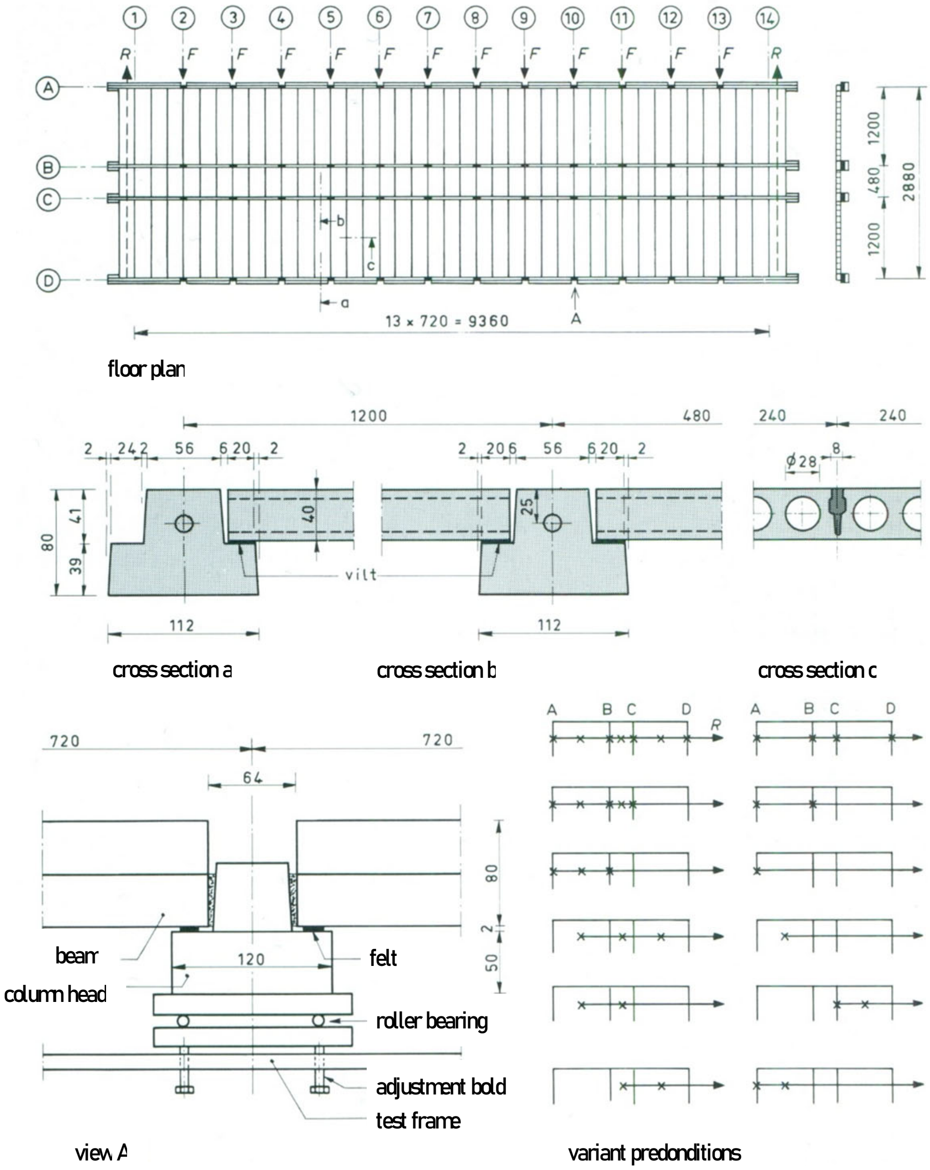


Fig. 3: Floor system made of prefabricated slabs [4]

The floor on scale 1:5 was composed of prefabricated slabs, beams and column heads [5]. The floor was loaded horizontally simulating forces due to wind, earthquake and misalignment of columns. Various parameters were tested: the type of ties (screws and cables), the supports of the perimeter elements (connected to shear wall or not), the type of loading (monotonic, repeated, alternate in two directions). The displacement of the elements, the cracking of the joints, the forces in the ties were measured. From theoretical and numerical analysis and measured results a model was established for the overall bearing behavior of the floor which can be used in hand calculations. After finishing the experiments, the floor was demounted without difficulty and reassembled again.

Some general recommendations resulted from the investigations:

- the connections between the elements are essential for horizontal rigidity
- the structure is statically determinate without indeterminate reserves
- a secondary system for excluding progressive collapse is necessary
- the joints have to be accessible and demountable
- joints should be filled with medium strength mortar
- shear walls or cores are necessary for overall stability of buildings.

Special investigations on connections in prefab concrete structures were also subject of publication [6, 7]. An international symposium was organized in Rotterdam in 1985 [8] which attracted many attendants and large attention. The idea of demountable concrete structures was pursued in Stuttgart resulting in a PhD thesis and various publications [9].

What is the ecological benefit of demountable concrete structures compared to in situ cast structures? The main benefit is that material and energy is saved when a building becomes obsolete [10]. The usual way to get rid of it is to demolish it and to put the waste material in a disposal site or, in the preferable case, to recycle it. However, demolition and recycling require much energy: the demolition consumes about 275 Mega Joule (MJ) per ton and the crushing of concrete another 85 MJ/t. For a building with 1,000 m^3 concrete, the energy consumption amounts to 1000 $m^3 \cdot 2.5\ t/m^3 \cdot (275 + 85)$ MJ/t = 900 Giga Joule (GJ). If the recycled material is reused as aggregates for new concrete, cement has to be used which has been produced with an energy input of about 3.5 GJ per ton of clinker. Further, the emission of CO_2 amounts to 600 kg/t of cement. If one assumes a clinker content of 200 kg/m^3 in the new concrete the energy demand would be 0.7 GJ for one m^3 of concrete and 120 kg CO_2 would be emitted. Additionally, the mixing of concrete requires another 8 MJ/m^3. So, it turns out that demolition and recycling require a great amount of energy and cause considerable air pollution. These negative ecological impacts can almost be avoided if a building is designed as a demountable structure and structural elements were reused.

3. PROTECTION OF ENVIRONMENT

When the German Water Resources Act was amended in the 1980ies installations for storage, handling and use of hazardous fluids have to be designed and built such that groundwater could not be polluted. Storage tanks have to have a second containment (secondary barrier, catching basin) which cannot be permeated by the fluid. There were various solutions made of steel, asphalt or clay. However, there were numerous existing installations with a concrete floor which were judged impervious but the government wanted to have a document indicating that the containment is safe. This demand was the reason that concrete permeability got much attention.

Concrete is a porous material which is not absolutely tight however, it is known that concrete can be impermeable for water. The question arose whether it is also impermeable for organic fluids, for acids and bases. The knowledge regarding this was very scarce. Another question concerned cracks in concrete, which crack width could be tolerated? Many questions triggered an extensive research program.

Porous materials can absorb fluids by capillary suction. The relation between absorbed mass and time is given by

$$m(t) = A\, t^{1/2} \tag{1}$$

and between penetration depth and time is given by

$$x(t) = B\, t^{1/2} \tag{2}$$

with the dimensions kg m^{-2} $s^{-1/2}$ for A and m $s^{-1/2}$ for B. The sorptivity S is absorption coefficient A divided by ρ with the dimension m $s^{-1/2}$. The coefficients can be converted as follows: $A = \varepsilon\rho B$, $B = S/\varepsilon$ and $\varepsilon = S/B$ with ε accessible porosity of concrete and ρ density of fluid, B is the penetration coefficient. These relations are valid as long as there is no chemical or physical interaction between fluid and concrete. Water does not strictly follow because it causes swelling of the matrix. Numerous organic and inorganic fluids have confirmed the relations [11].

The formulas are derived from capillary suction which depends on surface tension σ, contact angle θ and viscosity η of the fluid and the pore size of concrete. If r is the tube shape pore radius the relation becomes

$$B = (\sigma \cos\theta\, r/ 2\eta)^{1/2} \tag{3}$$

The formula consists of a term which relates to the fluid and a term which depends on concrete. The penetration of two fluids in the same concrete has the relation $(\sigma/\eta)^{1/2}$ if the contact angle is the same. In most cases the contact angle of wetting fluids can be taken as zero. Experimentally speaking it is enough to test only one fluid and calculate the penetration of other fluids from the known values of surface tension and viscosity.

The research resulted in a guideline of the DAfStb which is used to design containments of chemical installations and filling stations and other constructions for the protection of the environment [12]. The penetration anomaly of water has been discussed in [13].

From the research, it could be stated that concrete is a very useful material for barriers against contaminating fluids as long as it is uncracked. The flow through cracks can be calculated with

$$Q = w^3 \, \Delta p \, b \, / \, (\alpha \, \eta \, d) \qquad [m^3/s] \tag{4}$$

with w crack width, Δp pressure gradient, b crack length normal to flow direction, η dynamic viscosity, d crack length in flow direction. α is a coefficient which depends on type of concrete and can be taken as 100 approximately. (Hagen-Poiseulle's law would give 12.) So, through-cracks are very sensitive for tightness of a barrier, for example a crack with 0.1 mm width would lead to a fluid permeation which is 10.000 times the flow through uncracked concrete of one m^2. This is not the case for water which reacts with concrete and tightens the crack automatically.

The research comprised special questions like the influence of surface cracks, the de-contamination of concrete, the influence of moisture in the concrete, the two-phase flow of miscible and immiscible fluids [14, 15, 16, 17, 18, 19, 20].

4. COOPERATIVE RESEARCH PROJECTS: FOGIB, BIM, GABI

Within the cooperative research project FOGIB [21] the effect of several engineering and architectural disciplines on the design of a structure was studied. One aspect was the ecology [22]. Within the cooperative research project BIM (Life cycle of concrete structures) activities like demolition, crushing, recycling and reuse were investigated [23]. Finally, the project GABI was focused on the impact of the environment [24] with the aim to create the basis for EPDs (Ecological product declaration) and LCAs (Life cycle assessment) [25, 26, 27, 28]. All three projects were related to each other however, with different teams.

It is important to stress the durability of structures. All calculations on the ecological impact (foot-print) consider the lifetime of a product and it comes out that lifetime is a paramount parameter in these calculations since the ecological effect is always related on the lifetime. The longer a product is in service the smaller is the impact. That means that durability of materials and structures is really important. This can be expressed by the term “sustainability”.

5. CLOSURE

It is interesting to see how environmental issues are getting more popular. The strong demand for timber as construction material, the idea to re-use parts of prefabricated bridges after demounting, the high value of scrap, the banning of polymers, the collecting of glass and paper show that environment gets much more attention than in previous times.

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