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Biaxial hollow slab with innovative types of voids

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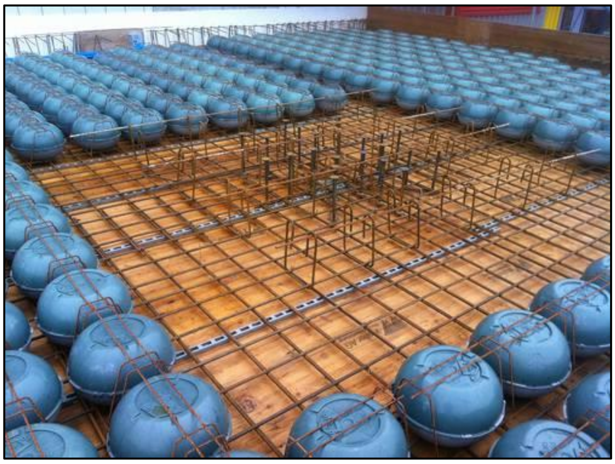
ABSTRACT



The invention of a new type of hollow core slabs was a breakthrough at the turn of 20th and 21st centuries. During the first decade there have been many studies on the feasibility of using the new technology.
This article presents the different types of hollow core slabs technology that have appeared over the last 15 years. As a result of the review the advantages of a new kind of hollow slab over a solid slab were summed up.
In this article the most famous of present examples of the new technology are also demonstrated.
All the experiments and studies carried out, mainly by manufacturer companies, are supported by regulations and local/international codes.

Contents

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1. Introduction

Hollow biaxial slabs, also known as biaxial voided slabs, are reinforced concrete slabs in which voids allow to reduce the amount (volume) of concrete.

The main disadvantage of concrete constructions, in case of horizontal slabs, is the high weight which limits the span. For this reason, basic research in the field of reinforced concrete structures have focused on enhancing the span, either by reducing the weight or overcoming concrete's natural weakness in tension.

The Pantheon in Rome, build 125 AD, is one of the most prominent examples in ancient history. Coffers, although not reinforced, were employed to lighten the weight of the dome [1].

The invention of the hollow slab was in 1950s. The hollow slabs are prefabricated, one-way spanning, concrete elements with hollow cylinders. Due to the prefabrication, these are inexpensive, and reduce building time, but can be used only in one-way spanning constructions, and must be supported by beams and/or fixed walls. The slab has been especially popular in countries where the emphasis of home construction has been on precast concrete, including Northern Europe and socialist countries of Eastern Europe. Precast concrete popularity is linked with low-seismic zones and more economical constructions because of fast building assembly, lower self-weight (less material), etc. In this article several types of the new innovative technology of production hollow slab is introduced.

2. Literature review

The relevance of this technology has been repeatedly noted in the articles [8, 15, 24]. The idea was to create a hollow biaxial slab with the same capabilities as a solid slab, but with considerably less weight due to the elimination of excess concrete. To date, the technology of structure of the slab is used in several companies [2, 5 - 7]. Also, what can we say of the analysis of the available literature, it is that the main difference between a solid slab and a hollow biaxial slab refers to shear resistance [18-37]. To view the structural behavior of this slab can be by reading the [9, 10, 11, 15, 20, 21, 23].

3. Purposes and objectives

An assumption has been made about the necessity of further research of modern technologies for creating hollow slabs. Various producer organizations of this kind of slab and the main differences between them should be reviewed and summarized. Also it is necessary to allocate the available advantages and disadvantages of the new technology, and in the future to compare with the currently known methods. On this basis, we should determine the feasibility of new technologies.

4. Technology review

4.1 Various examples

Various types of hollow slab systems existing over the world are reviewed and summarized below:

Airdeck

The Airdeck concept was patented in 2003 and comprises an inverted plastic injection moulded element which is vibrated into the lower slab during the production process by a robotic arm (figures 1,2). The advantage of this system is that no retaining mesh is required to hold down the voiding elements during on site pouring of the second layer. As the boxes can be nested there are clear transport advantages versus other voiding systems. The static calculations are performed according to standard Eurocode 2 norms [3].

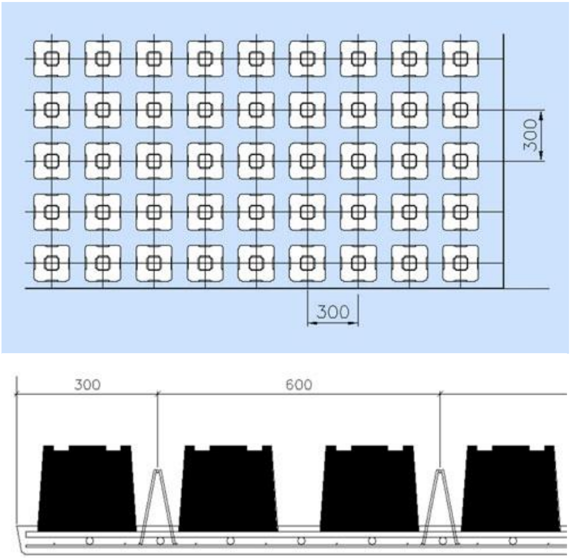


Figure 1. Geometry of the Airdeck slab [2]

Figure 2. Example of Airdeck slab construction [2]

Cobiax

The Cobiax system makes use of the same hollow slab principles of creating voids within the concrete slabs to lighten the building structures (figures 3, 4). Elliptical & torus shaped hollow plastic members, termed as hollow formers, are held in place by a light metal mesh for easy installation between the top and bottom reinforcement layers of a concrete slab [12].

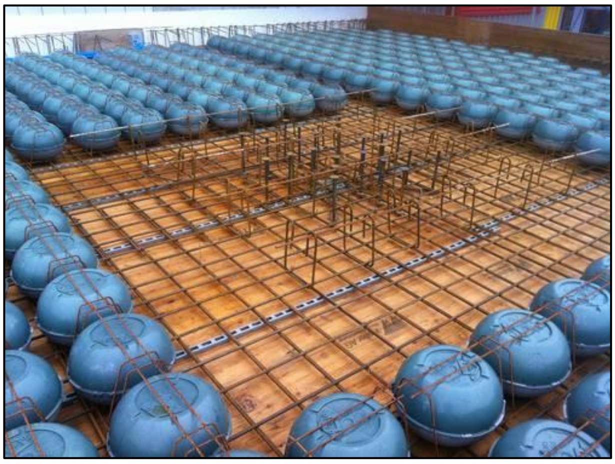


Figure 3. Prefabrication of Cobiax slab [6]

Figure 4. Example of installation of Cobiax slab [7]

U-boot

In 2001 an Italian engineer, Roberto Il Grande, developed and patented a new system of hollow formers, in order to decrease the transportation costs (and CO_2 production). The U-Boot formwork is a modular element made of re-cycled plastic for use in building lighter structures in reinforced concrete cast at the work-site (figures 5-9). The biggest advantage of U-boot is that it is stackable. A truck of U-boot® means approximately 5000 m^2 of slab, once hollow formers are laid down at building site. The second innovation is the shape: U-boot® creates a grid of orthogonal "I" beams, so the calculation of the reinforcement can be effected by any static engineer according to Eurocode, British Standards or any local standard.

U-boot® earliest projects were executed in 2002 and since that time it has been used all over the world [7].

U-boot® system can be combined with other technologies like pre-fabricated slabs and post tensioned steel. The technology of hollow slabs with post tensioned steel reduces the weight of slab and its thickness.

Figures 5-7. U-boot® slab application [7]

Figure 8. U-boot® voiding element [7]

Figure 9. Constructing U-boot® slab on a site [7]

Polystyrene voiding blocks

The classical method for reducing weight of structural decks is the use of polystyrene blocks to reduce the amount of concrete poured on site. This requires large expenditures of human labor (figure 10).

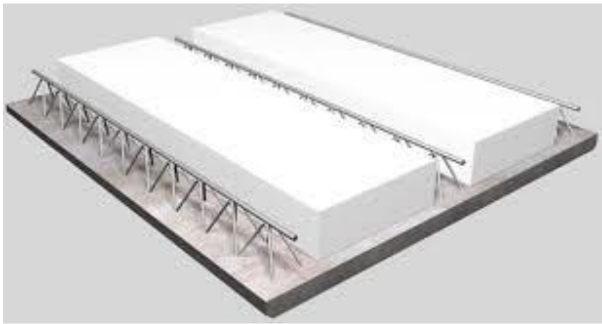


Figure10. Examples of Voiding blocks technology

BubbleDeck

In the middle of 1990s, a new system was invented, eliminating the above problems (figures 11, 12). The so called BubbleDeck® technology invented by Jørgen Breuning, locks ellipsoids between the top and bottom reinforcement meshes, thereby creating a natural cell structure, acting like a solid slab. For the first time a hollow biaxial slab is created with the same capabilities as a solid slab, but with considerably less weight due to the elimination of superfluous concrete. Design of this type of the slab is based on the euro and the British codes.

Consider the composition, structural behavior in theory, advantages and the fields of application in the example of BubbleDeck technology to find out benefits of the new kind of hollow slab over the common solid slab.

4.2 Composition of the system

The geometry of the BubbleDeck slab is a certain size ellipsoids, disposed at a certain distance from each other, fixed by reinforcing top, bottom and side meshes. All geometric parameters of the slab can be described by a single parameter, the modulus named “A”. Modulus and corresponding deck heights are manufactured in steps (modulus in steps of 25 mm, and effective heights in steps of 50 mm) [5].

In principle, the fixing of the ellipsoids can be done in various ways, but only the reinforcement meshes reduces unnecessary material consumption and ensures optimal geometric ratio between concrete, reinforcement and voids.

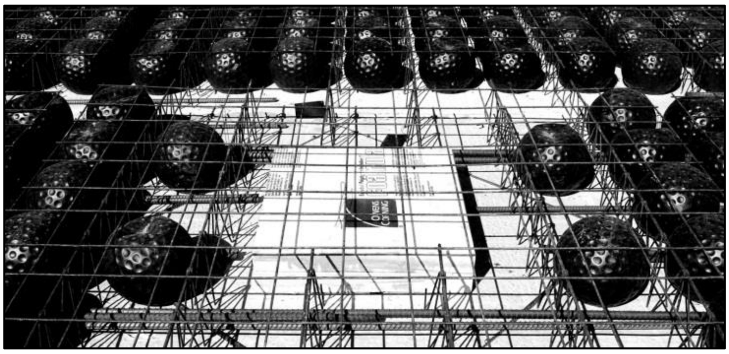


Figure 11. Prefabrication of BubbleDeck slab [5]

Figure 12. Concreting slab on site [5]

Voids are located in the middle of the cross section where the concrete has a limited effect, while retaining the solid sections of the top and bottom parts, where high stresses may exist. Thus, the slab is fully functional with respect to both positive and negative bending.

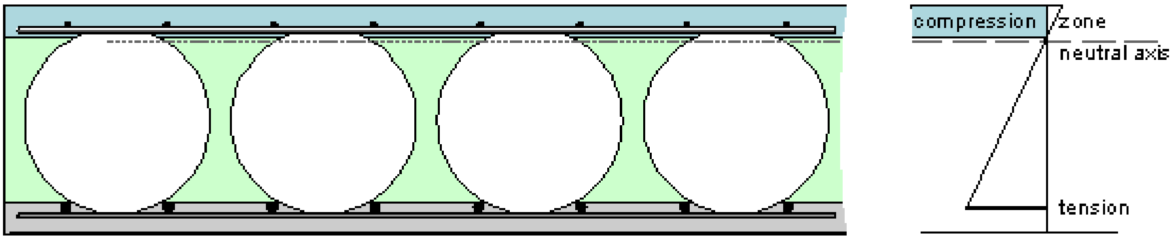


Figure 13. Structure of BubbleDeck slab, cross-section view [5]

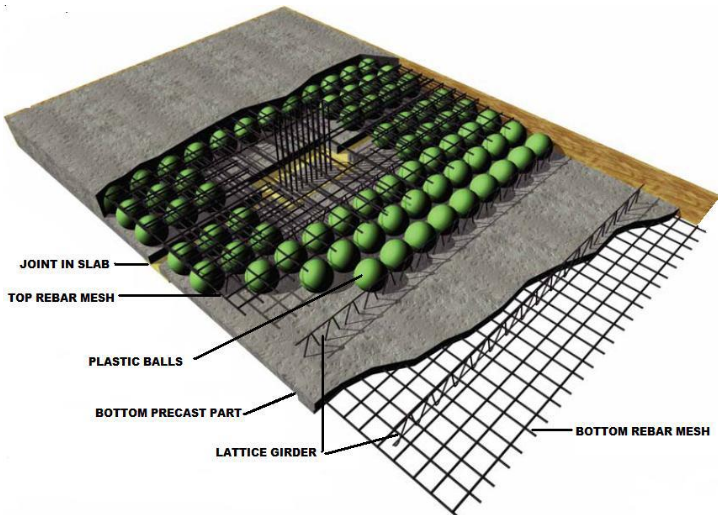


Figure 14. Structure of BubbleDeck slab by layers [64]

4.3 Behavior of the slab

In principle, BubbleDeck slabs acts like solid slabs. Designing as a result can be obtained as solid slabs, just with a smaller load, corresponding to the reduced amount of concrete. Extensive studies in accordance with Eurocodes are made at universities in Germany, Netherlands and Denmark, concluding that Bubbledeck slab behaves like a solid slab. [8-16]

It is important to emphasize the differences in static calculations between different hollow slabs. While a true biaxial slab as the BubbleDeck system must be calculated as a solid slab, ribbed slab systems, like the U-boot system, consisting of a grid of orthogonal "I" beams, must be calculated as beams.

The BubbleDeck® technology is directly incorporated in national standards, such as the CUR [17] in the Netherlands.

4.4 Carrying capacity

A solid slab can only carry approximately one third of its own weight, and have problems with long spans due to its high weight. The investigations of BubbleDeck's biaxial deck allow to solve this problem by eliminating 35% of concrete, while maintaining strength [38]. Test have shown that for a BubbleDeck slab with the same load-carrying capacity can be used only 50% of the concrete required for a solid slab, or with the same thickness of a BubbleDeck slab the load-carrying capacity can be increased up two times by using 65% of concrete [39].

4.5 Shear resistance

The main difference between a solid slab and a hollow biaxial slab is a shear resistance. Due to the reduced concrete volume, the shear resistance will also be reduced.

For a BubbleDeck slab the shear resistance is proportional to the amount of concrete, as the special geometry shaped by the ellipsoidal voids acts like the famous Roman arch, hence enabling all concrete to be effective. Notice, this is only valid when considering the BubbleDeck technology. Other types of hollow biaxial slabs have reduced resistances towards shear, local punching and fire.

In practice, according to [18-24] the reduced shear resistance will not lead to problems, as balls are simply left out where the shear is high, at columns and walls. The recommendations made as a result of the studies on punching shear capacity can be read in [25-36].

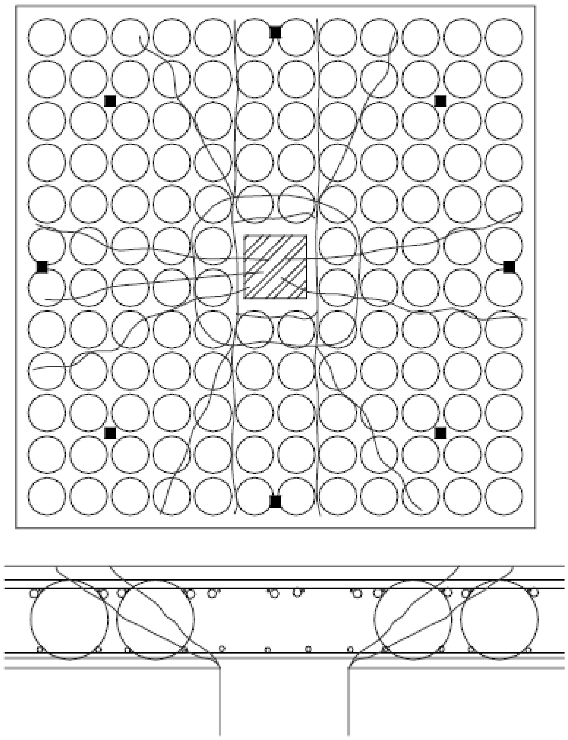


Figure 15. Top and cross-section view of crack pattern after the punching failure [23].

Figure 16. Floor to Column Connection [23].

4.6 Fire resistance

As a BubbleDeck slab acts like a solid slab, the fire resistance is just a matter of the amount of concrete layer. The fire resistance is dependent on the temperature in the rebars and hence the transport of heat [37]. As the top and bottom of the BubbleDeck slab is solid, and the rebars are placed in this solid part, the fire resistance can be designed according to demands. According to [38] examinations carried out in accordance with ISO 834 and showed that fire resistance lasts 60 to 180 minutes and smoke resistance is 1.5 times the fire resistance. The studies on fire resistance of hollow slab can be read in [40-42].

4.7 Tests on sound resistance

Tests have been carried out in Germany [43], UK [44] and the Netherlands [45] according to ISO 140-4:1998, ISO 140-7:1998, ISO 717-1:1997 and ISO 717-2:1997 measuring impact and airborne sound. These tests show that 230 mm and thicker BubbleDeck® slabs can meet the national rules.

4.8 Qualities

There exist different approaches and opinions of design methods - but some general guiding principles are:

- Low weight/stiffness ratio – influence of impact is proportional with weight;
- Simplicity and symmetry and uniform extent – Lessen the impact effect Uniform and continuous distribution/flow of forces;
- Monolithic, continuous and ductile structure.
- The BubbleDeck® system fulfil these principles:
  - Saves 35% weight compared to a corresponding solid slab – equal stiffnes;
  - Simple, monolithic behaviour, uniform and continuous distribution of Forces;
  - Max ductile structure - increased ductility due to increased strength/weight ratio;

The studies on seismic behavior can be read in [46, 47].

4.9 General benefits of the system

Different building types have different advantages, but general benefits in contrast to solid slabs are:

- Design Freedom – flexible design easily adapts to irregular and curved plan layouts, longer spans and fewer supports [38];
- Downstand beams and bearing walls eliminated – quicker and cheaper erection of walls and services [48];
- Reducing overall costs – the material consumption is reduced and construction is faster [38];
- Reduced Dead Weight – 35% removed allowing smaller foundation sizes;
- Longer spans between columns – up to 50% further than traditional structures;
- Construction is less weather dependent – there is no need of erection load-bearing blockwork to support floor slabs, which is taken of the critical path [48];
- Reduced foundation sizes – there is up to 50% less structural dead-weight;
- Reduced concrete usage – 1 kg of recycled plastic replaces 100 kg of concrete [48];
- Environmentally Green and Sustainable – reduced energy & carbon emissions. 8% of global CO_2 emissions are due to cement production. 1 ton of cement:
  - Emits 1 ton of carbon dioxide (CO_2) [49-52];
  - Consumes 5 million BTU of energy [53];
  - Uses 2 tons of raw materials [54].

Due to the BubbleDeck technology's green credentials, the use of the BubbleDeck system qualifies for LEED points in North America [55, 56].

4.10 Applicability of the slab

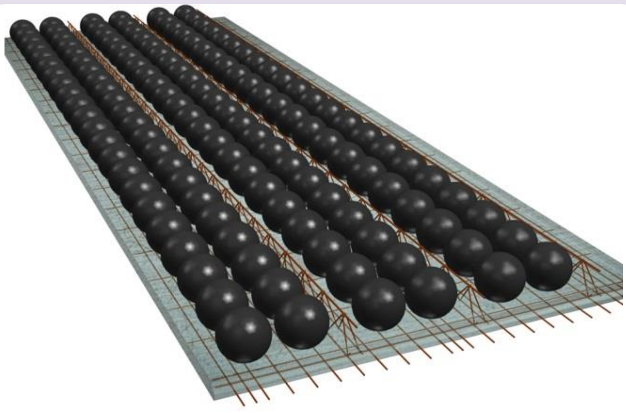
The Biaxial BubbleDeck® can be implemented in three versions according to degree of prefabrication:

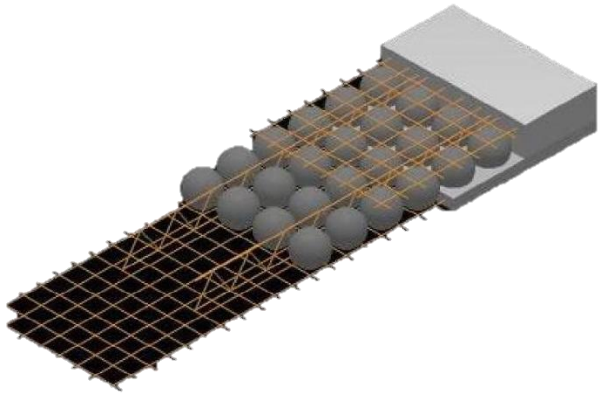
- “Reinforcement modules”: Comprising prefabricated “bubble-lattice” sandwich elements to be placed on traditional formwork. Building time is reduced compared to conventional on site construction.

Suitable for the majority of new-build projects, also suspended ground floor slabs and alteration/refurbishing projects.

- “Filigree elements”: Where the bottom side of the 'bubble-lattice' unit is furnished with a pre-cast concrete layer which replaces the horizontal part of the formwork on the building site, optimizing both building time and quality by prefabrication.

Acts directly like a seamless ceiling. Suitable for the majority of new-build projects.





Figures 17, 18. Example of “filigree element” prefabrication [65].

“Finished elements”: Finished panels, complete precast slab elements. These can be used for limited areas such as balconies or staircases (figures 17, 18).

The BubbleDeck technology can benefit most buildings. However, as it is a biaxial deck technology, the use will focus on biaxial slab designs.

Functional applicability: Residential living, offices, utility and industrial buildings.

Environmental applicability:

– Substantial reduction in materials and transportation;
– Less emission and energy consumption;
– Every component can be recycled. Easy demolition.

4.11 Installation of the system

The BubbleDeck concept simplifies the placement of installations like ducts and heating/cooling systems directly in the slab. This enhances the nature of the slim flat slab structure. The tubes can either be placed in the bubble-lattice as prefab, or onsite before concreting. Thermal heating/cooling in slabs can substantial reduce the energy consumption (figures 19, 20). The studies can be read in [58-63].

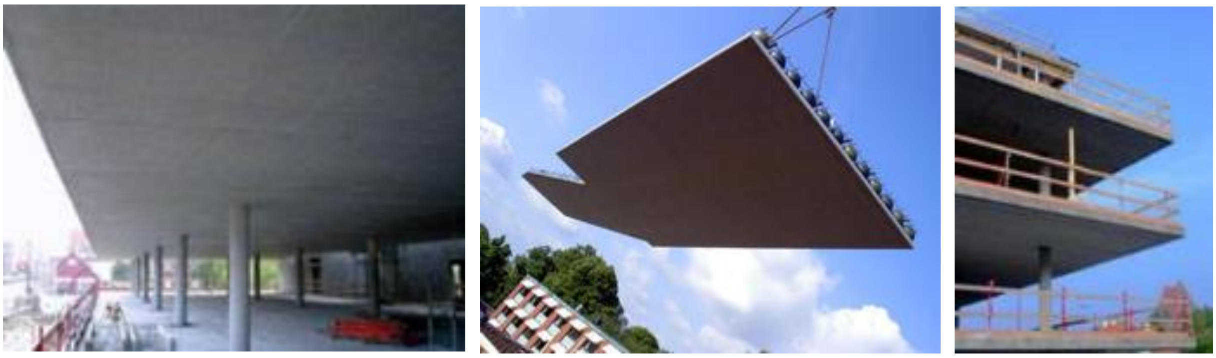
Figures 19, 20. Examples of heating/cooling tubes system [63].

4.12 Examples

The possibilities of the technology are shown in the following examples of constructions:

Figure 21. Altra Sede, Milan, Itlay. Cobiax technology [66].

Architects: Caputo Partnership, Milan and Pei Cobb Freed & Partn. New York;
Structural Eng.: Prof. Ing. Franco Mola, Bari and Thornton Tomasetti, New York;
Contractor: Consorzio Torre;
380,000 sf on 39 floors; 33 ft spans with 13.75" slabs.



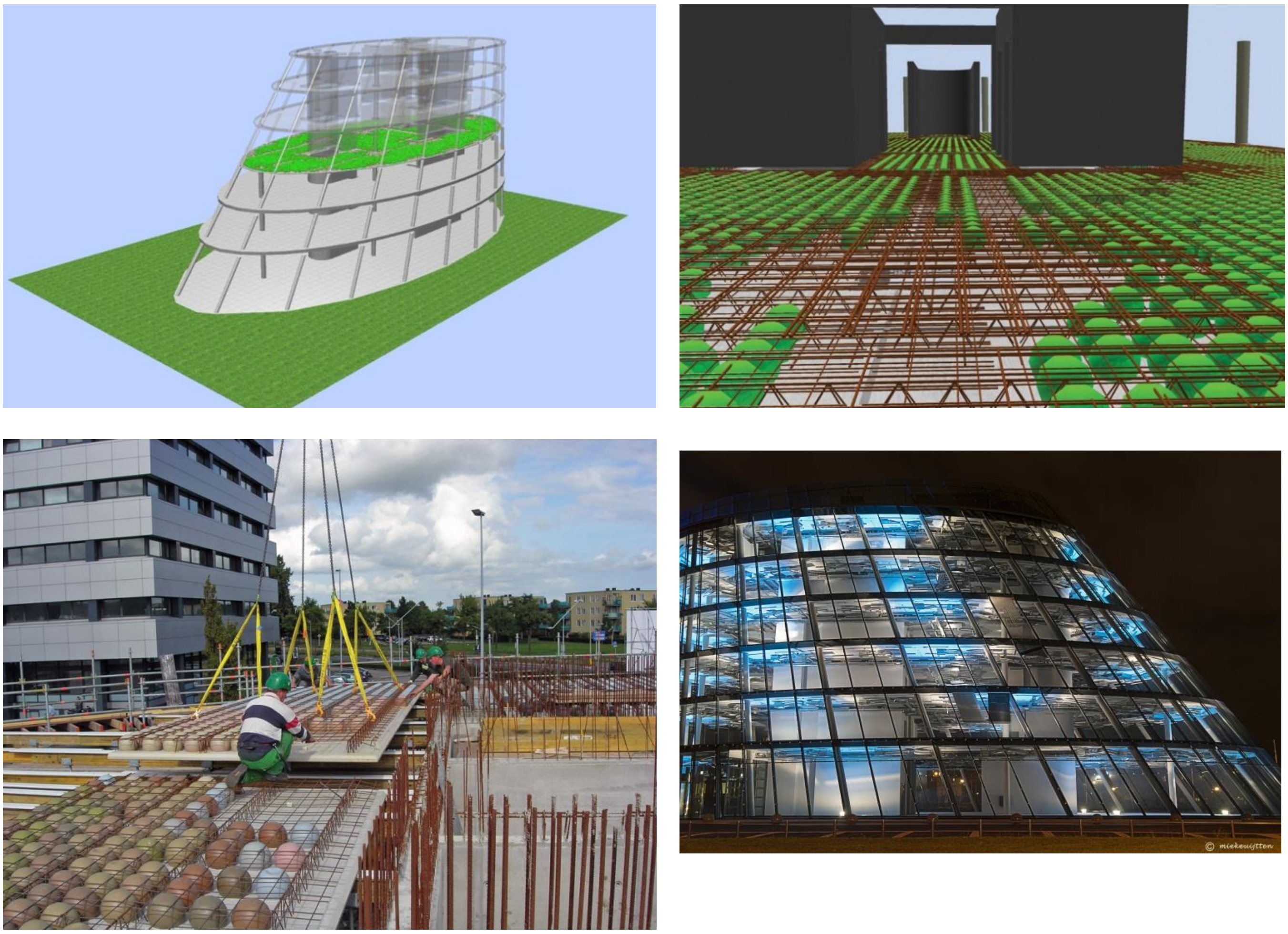
Figures 22-24. City Hall and Offices, Glostrup in Denmark. BubbleDeck technology [67]

Figures 25, 26. City Life, Italy - Lightened biaxial slabs in reinforced concrete. U-boot technology [68]

Figure 27. Hospital, Italy. U-boot [68]

Figure 28. Multi-storey cinema, Korolev, Russia. U-boot [68]

Figure 29. Quom, Iran. U-boot [68]



Figures 30-33. The Curve, Amsterdam, Netherlands. BubbleDeck [69]


Figures 34, 35. LaBahn Arena, Wisconsin, USA. BubbleDeck [70]

Figure 36. LaBahn Arena, Wisconsin, USA. BubbleDeck [71]

Figure 37. LaBahn Arena, Wisconsin, USA - Concrete pour into precast bed complete [71]

Figure 38. LaBahn Arena, Wisconsin, USA – Construction workers pouring concrete over the bubbles to form the reinforced slab of steel, air, and concrete [71]


Figures 39, 40. The Millenium Tower, Rotterdam, Netherlands – One of the first structures to use BubbleDeck. 35-storey, 130.8 m height [72]

4.13 Prizes and awards

BubbleDeck as the oldest producer received more prizes and recognitions:

- The Industrial Environmental Prize, the Netherlands 1999
- The Stubeco Building Prize for Execution, the Netherlands 2000
- Innovation Award, the Netherlands 2000
- RIO Award, Germany 2003
- “Building of the Year” for Office buildings, Denmark 2004
- Jersey Construction Awards: “Best Use of Innovation”, Jersey 2005
- “Best New Product” Award at Design/Form&Function, Australia 2009
- “Eco Product Award”, Malaysia 2013.

Cobiax technology has won such prizes:

- Swiss Environmental Prize for Technical Innovation, Switzerland 2010;
- German Material Efficiency Prize, Germany 2011.

5. Conclusion

According to the analysis such conclusion can be drawn:

1. Due to the fact, that the structural behavior of this new kind of monolithic flat slab is the same as for solid slab, excluding slab-edge column connection, we surely can talk about appropriateness of use and advantages of the new technology.

2. Concrete usage is reduced – 1 kg of recycled plastic replaces 100 kg of concrete. Reducing material consumption made it possible to make the construction time faster, to reduce the overall costs. Besides that, it has led to reduce dead weight up to 50%, which allow creating foundation sizes smaller.

3. The technology is environmentally green and sustainable. Avoiding the cement production allows to reduce global CO_2 emissions. The use of the BubbleDeck system qualifies for LEED points in North America.

4. This technology is very prospective in modern construction and perhaps future of civil engineering belongs to this new kind of hollow slab.

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Двухосная пустотная плита с инновационными видами пустот

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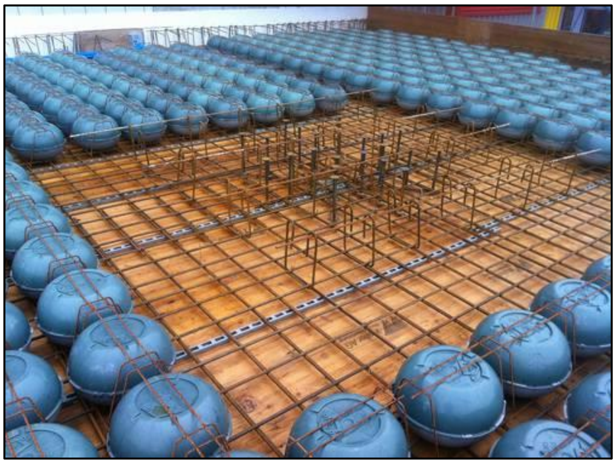
пустотная плита,
пузырьковые перекрытия,
LEED,
bubbledeck,
cobiax,
u-boot.

АННОТАЦИЯ



Изобретение нового вида пустотных плит, работающих не по одному, а двум направлениям, стало настоящим прорывом на рубеже 20 и 21 веков. В течение первого десятилетия было проведено множество исследований по целесообразности применения новой технологии. В данной статье представлены различные виды двухосных пустотных плит, технологии создания которых появлялись в течение последних 15 лет. В результате обзора выявлены преимущества новых видов пустотной плиты перед обычной цельной плитой. Также, в статье продемонстрированы наиболее известные на сегодняшний день примеры применения новой технологии. Все опыты и исследования, проведенные, в основном, компаниями-производителями, подкреплены нормативными актами и документами.

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