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Efficiency of applying sustainable technology of bubbledeck technology in concrete in Russia

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ABSTRACT

The idea of optimization concrete use, reducing its amount and applying new technologies, is not novel one. During the last three decades there were several studies and projects, in which concepts of slab with voids were used. Bubbledeck technology consists of hollow slabs and plastic balls in it, which serves for reducing of concrete volume. In this article Bubbledeck is estimated for Russian construction market. Possibility and efficiency of appliance this technology is assessed. Construction methods, sustainability and properties are considered. Inputs of bubble’s construction, concrete and technology are compared with the costs of using conventional concrete. Basing on these data suggestions for effective technology implementation and appliance are given.

Content

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1. Introduction

The search for new methods that improve the quality and velocity of construction industry is one theme approached in all World. The economic scenario nowadays, with strong market competitions to reduce coast, deadlines and efficient in buildings without compromising the quality, in the end, could be the big differential for companies to be successful. In this way, several different types of structures were created to improve the construction conditions, as precast concrete, metallic structure, hallow or voided slabs, among others.

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)" [1]

In this way, in 1980s, the engineer Jorgen Breuning, created one slab with plastic bubbles inside the slab, inserted evenly between two steel armatures that fill the zone previous occupied by the no structural concrete. Thus, the slab have the same capabilities as a conventional solid slab but it is possible to reduce between 25% until 30% the weight of slab when compare with the reinforced concrete [2]. Becoming one excellent opportunity when are wanted do achieve lightweight structures saving construction costs and being more sustainable [3].

There are three types of Bubbledeck's slab that can be chosen, only the armatures and the bubbles, the precast Bubbledeck and the whole piece, the most common is Bubbledeck precast slab. This one, consist in one Bubble between two armatures, like said before, but with one thickness of 6 centimeters on concrete, eliminating the necessity of forms to realize the concrete in the construction.

Whereas, there are some technology exclusivity that should be careful about. The first one is that the space construction should be big to stock the Bubbledeck piece inside it or the production planning and transportation have to work perfectly to not disrupt the construction progress. One thing is that it is necessary to use machines to hoist the precast Bubbledeck, such as a Munck truck or a crane [7].

The aim of this study is to estimate possibility and efficiency of applying the Bubbledeck technology in Russia. To accomplish this aim the following objectives were figured out:

1. Assessment of properties, behavior and sustainability of Bubbledeck according to Russian conditions.
2. Determination of feasibility, considering all costs for Bubbledeck production in comparison with conventional concrete cost.
3. Suggestions for technology implementation and appliance in Russia.

2. Bubbledeck Technology

2.1 Properties

The Bubbledeck precast slab is one hallow slab, with bubble inside the concrete, like said before. The precast slab is realized in one factory environment and is formed by:

- Steel: Fabricated as a rebar mesh and lattice girder to reinforce the structure and support the bubbles
- Plastic Spheres (Bubbles): Made by plastic, in the most part Polypropylene (thermoplastic[1]), can have different sizes the according of the project necessity. In addition, can be used one reasonable percent of recycle plastic, in general around 30%.
- Concrete: Standard Portland cement with maximum aggregate proportion of 3/4 in.

[1]Thermoplastics plastic: can be melted by heat, and formed in shaped containers called moulds. After the liquid plastic has cooled, it sets to form a solid material. A thermoplastic is a type of plastic that can be heated and moulded numerous times, because of that can be recycled.

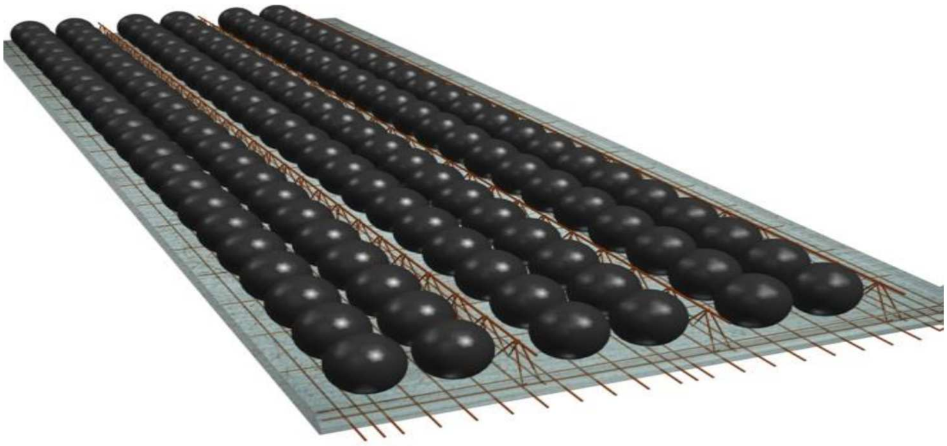

Figure 1. Example of prefabrication

2.2 Assumptions for calculation and slab behaviour

To calculate one Bubbledeck Slab it common to use the aid of conventional methods of massive slabs. Nevertheless, are already in Germany and United Kingdom Bubbledeck's Standards, as DIN 1045 (2001) and EN 13747 (2005) that present the requirements necessary to scale out the Bubbledeck slab.

The Bubbledeck intended to be a flat, two-way spanning slab supported directly by columns, which is mean, without beams. Then, the first criteria utilized to define the type of Bubbledeck panel is the L/d Ratio, being "L" the length of the smallest span and "d" the thickness of the slab.

Therefore, the Bubbldeck International, suggest:

L/d ≤ 30 – for simply supported, single spans

L/d ≤ 41 – for continuously supported, multiple spans

L/d ≤ 10.5 – for cantilevers

In addition, five standard thickness of slabs is common, which vary from 230 mm to 450 mm and is function of the length span.

Table 1. Slab Parameters

Bubbledeck Type	Bubble Diameters [cm]	Minimum Slab Thickness [cm]	Center-to-center span bubbles [cm]	Length between columns [m]
BD 230	18	23	20	7 to 10
BD280	22.5	28	25	8 to 12
BD340	27	34	30	9 to 14
BD390	31.5	39	35	10 to 16
BD450	36	45	45	11 to 18

Then, the Bubbledeck International have compared the stiffness between Bubbledeck and Conventional Slab (Conventional), in situation of the same Strength, Bending Stiffness and concrete volume, as shown in the table.

Table 2. Stiffness Comparison of Bubbledeck and Solid Slab (on the condition of the same amount of steel)

(in % of solid deck)	*Same Strength*	*Same Bending Stiffness*	*Same Concrete Volume*
Strength	100	105	150*
Bending Stiffness	87	100	300
Volume of Concrete	66	69	100

Therefore, analysis have proven that under the same strength, Bubbledeck has 87% of the Bending Stiffness of one solid slab using only 66% of concrete. Then, the deflection in Bubbledeck slab is higher than a solid slab under the same forces. On the other hand, the light Bubbledeck weight compensated the bending stiffness resulting in one higher carrying capacity. In addition, with the same amount of concrete, Bubbledeck present higher capacity and bending stiffness comparing with solid slab [4].

The shear capacity of concrete is function always of the mass of concrete, because of that, the Bubbledeck shear resistance is considerably reduced when compared with on slid Slab. Thereafter, another risk phenomenon that have to be attentional in this slab is punching shear that happens when one localized forces is applied [5].

2.3 Conditions

Definitely, Bubbledeck precast slab do not need special conditions to be implanted. Nowadays the technology is presented in more than 32 countries in Europe and Canadian, behaving in the same way from the countries of tropical climate until temperate. This occurs because does not matter the climate to implant this type of slab, like one precast concrete, with the same characteristics, but with bubbles inside.

However, places where windy and rain a lot, the planning may be impacted by the need to interrupt the use of hoisting machine, such as crane, in strong winds due to safety concerns [6].

The equipment is, in general, necessary to use in this technology are the same of precast concrete, do not need any special one.

The main challenge of the technology it is the learning process, as all new technologies. When a new type of project appears, sometimes the Companies are afraid to invest in one thing that could have some risk aggregate, because the not knowledge. However, the projects that have already been done, shows that because it is one standardized and repetitive activity, the production starts median, but after the adaption and automatization of the process by workers, it behaves highly efficiently [8].

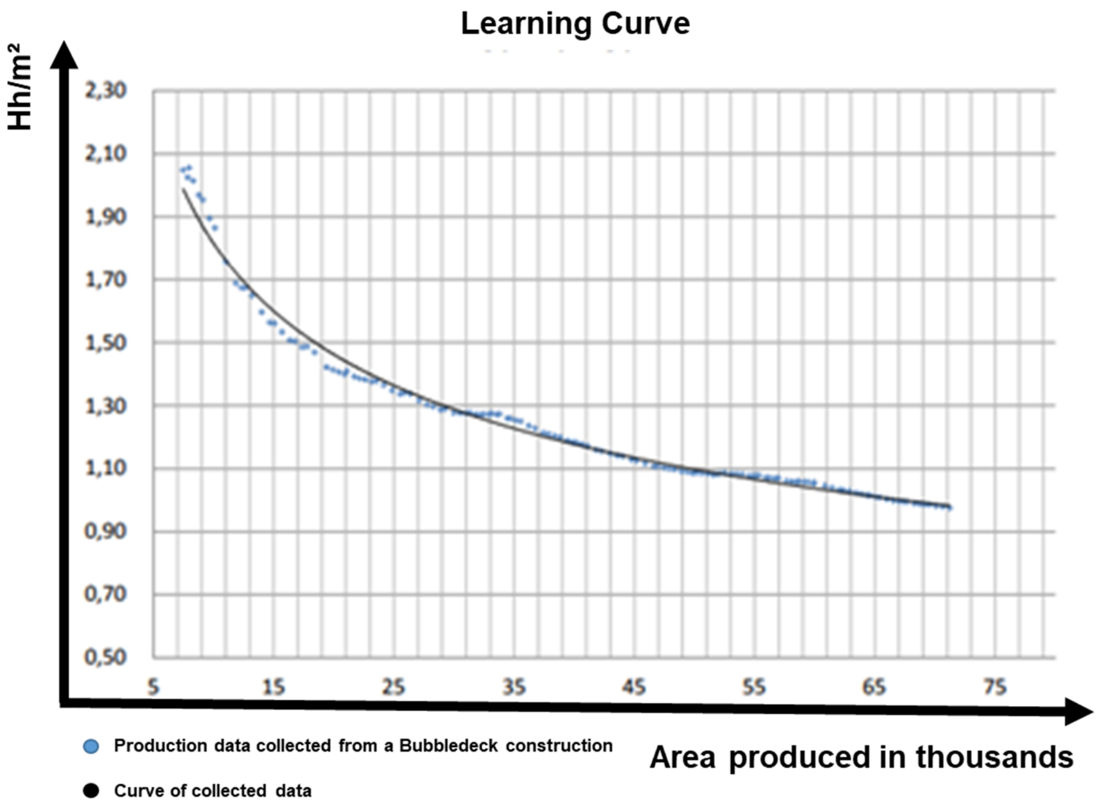

Figure 2. Learning Curve

Thereafter, there are some conditions that could influence the Bubbledeck precast slab productivity, these factors can be divided in qualitative factors, which concern about the quality of work and facility and the quantitative [9], which mean about the area and production numbers, as shown in the table:

Table 3. Factors that influence Bubbledeck slab production

Factors	Aspects
Qualitativies	
Concrete workability	More fluid, more easy to work and faster
Climate Conditions	Days without strong rain and windy are more productive
Production planning	The production sequence and stoke
Production Line	The organization of the precast slab
Quantitatives	
Square produticed	Learn, high the productivity
Stoke space	Small places limit the production
Velocity to aplly precast slab	Slow velocity limit the production

2.4 Sustainability

The Bubbledeck system is qualified for the most important seal of sustainability in North America, the LEED seal. According to the Bubbledeck International, 1 kg of plastics replaces 100kg of concrete. In this way, using less concrete than solid slab, it is possible to save around 40 kg of CO^2 emission in 1 m^2 of construction.

Then, the amount of some resources as water, sand, stone, cement is also reduced and the bubbles can be made by one reasonable amount of recycle plastic.

Generally, for every 5000 m^2 of Bubbledeck slab, the owner can save the according of Bubbledeck International:

- 1000 m^2 of on-site concrete
- 166 concrete truck trips
- 1.798 tons of foundation load, or 19 less piles
- 1.745 GJ of energy used in concrete production and transportation
- 278 tons of CO2 emissions
- 250 m^3 of wood – around 84 trees

3. Bubbledeck cost efficiency

There are several constituents in the Bubbledeck slab: precast concrete slab, polypropylene balls, concrete poured in situ and reinforcement of the structure and for ball`s support. To estimate the cost of the slab, prices of the elements are evaluated separately. In this paper manufacturing and transportation costs are not considered.

The first point is estimation of the cost of the ball`s material. To provide an adequate durability, resistance to extreme temperature, high water resistance and non-interaction with chemicals a high-density polyethylene is used. In Russia this type of material is produced in Moscow and is called PE2NT22 12 in accordance with the Russian rules (TU 2243-176-00203335-2007) [10]. It has the following properties (Table 4).

Table 4. Properties of PE2NT22 12 for the balls producing

Parameter name	Value
Density, g/sm^3	0.963±0.004
Melt flow rate (t=190 ^{0}C, F=2.16kg), g/10min	6-9
Tensile strength, MPa	At least 28
Breaking strength, MPa	At least 17
Relative breaking elongation, %	At least 500
Time of stress cracking resistance, hours	At least 30

All estimation is carried out for the slab, which width is 250 cm, length is 800 cm and total height is 45 cm (precast slab`s height is 6 cm, in situ slab`s height is 39 cm).

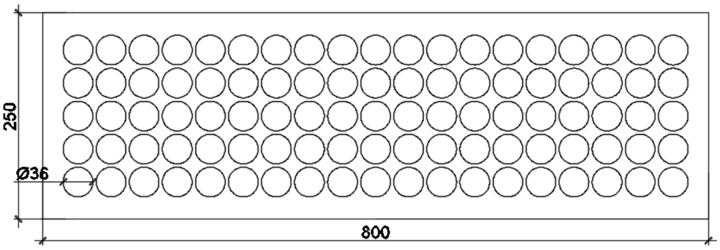

Figure 3. The parameters of the hollow slab

Therefore, the volume of the one ball can be estimated by the following formula:

$$V_b = \frac{4}{3}\pi\left(R_{ext}^3 - R_{\text{int}}^3\right) = \frac{4}{3}\pi\left(18^3 - 17.5^3\right) = 1979.73\,\text{cm},$$

Number of balls in, for example, in this precast slab is equal to 95. Their parameters are:

- Diameter is 36 cm
- Thickness of the ball is 0.5 cm

where R_{ext} – radius of the external ball\`s surface,
R_{int} – radius of the internal ball\`s surface.
Average density of the PE2NT22 12 is ρ = 0.963 g/cm^3, as a result mass of the one ball is as followed:

$$m = V_b \cdot \rho = 1979.73 \cdot 0.963 = 1906.5g \approx 1.9\,\text{kg},$$

where V_b – volume of the one ball,
ρ - density of the polyethylene, used for ball\`s construction.

Total number of the balls in the slab with parameters as mentioned is 95. Basing on the mass of one ball, total mass can be calculated by the following formula:

$$M = m \cdot N = 1.9 \cdot 95 = 180.5\,\text{kg},$$

where M – total mass of the balls in one slab,
m – the mass of the one ball,
N – the number of the balls in the slab.

Basing on the prices, that are given by an operating company «PolimerInvest» placed in Moscow city, it can be concluded that the average cost of the polyethylene PE2NT22 12 is equal to 70 rubles per kg [12]. Consequently, total price of the material for the bubbles is estimated by the formula:

$$C_b = c_b \cdot M = 70 \cdot 180.5 = 12635\,\text{RUB},$$

where C_b – total cost of the material for the balls,
c_b – the cost of the one kg of the PE2NT22 12.

The second point is estimation of the cost of concrete, used for bubbledeck slab. There are two layers of the concrete, used for construction: precast concrete slab and concrete poured in situ. The cost of the precast slab is around $C_{pr.c}$ = 20000 ₽. It is made on a by-order basis and approximate price was given basing on the price of the precast slab, manufactured on a concrete factory in Rzhev with parameters L=808 cm, W=149.5 cm and H=22 cm [13].

Volume of the concrete poured in situ is estimated by the formula:

$$V_c = h \cdot a \cdot b - V_b \cdot N = 39 \cdot 250 \cdot 800 - 1979.73 \cdot 95 = 7611925.65cm^3 \approx 7.61m^3,$$

where h – height of the concrete slab poured in situ,
a – width of the slab,
b – length of the slab.

According to the prices in Russia, average cost of the concrete B25 (M350) poured in situ is around 3500 rubles per m^3. Therefore, total cost can be calculated:

$$C_c = V_c \cdot c_c = 7.61 \cdot 3500 = 26635\,\text{RUB},$$

where c_c – average cost of the one m^3 of the concrete.

The third point is estimation of the cost of reinforcement, used for bubbledeck slab. It can be said that for one m^3 of the Bubbledeck slab the following amount of reinforcement is necessary:

- Inferior Reinforcement ratio: 24.56kg/m^3 slab
- Superior Reinforcement ratio: 14.68kg/m^3 slab
- Connection Reinforcement ratio: 12.8kg/m^3 slab

To sum up, overall value of the reinforcement for 1 m³ is 52.04 kg/m³ slab. For the slab with given parameters: the width is 250 cm, the length is 800 cm and the total height is 45 cm the total weight can be estimated as:

$$W_r = w_r \cdot a \cdot b \cdot H = 52.04 \cdot 2.5 \cdot 8.0 \cdot 0.45 = 468.36kg = 0.468t ,$$

where W_r – total weight of the reinforcement,

w_r – weight of the reinforcement for 1 m³ of the concrete,

H – total height of the slab.

According to the prices in Russia, average cost of the reinforcement A500C D=16 is around 32000 rubles per ton [14]. Therefore, total cost can be calculated:

$$C_r = W_r \cdot c_r = 0.468 \cdot 32000 = 14976 \text{ RUB},$$

where C_r – total cost of the reinforcement for the bubbledeck slab,

c_r – average cost of the steel bars.

Therefore, overall cost of the materials for construction of the bubbledeck slab with the parameters mentioned above is as follows:

$$C_{bb} = C_b + C_c + C_{pr.c} + C_r = 12635 + 20000 + 26635 + 14976 = 74246 \text{ RUB}.$$

Cost of the conventional concrete slab is calculated for comparison with the Bubbledeck slab and assessment of its cost efficiency. Conventional slab has the following parameters: the width is 250 cm, the length is 800 cm and the total height is 30 cm. All the concrete is poured in situ and has the same class B25. In spite of the fact that forces are not considered, reinforcement is set to A500C D=16 the ratio of the reinforcement in the slab is about 0.085 ton per m³ [15]. Basing on these assumptions the cost of the conventional concrete slab is calculated by the following formula:

$$C_{cc} = a_{cc} \cdot b_{cc} \cdot H_{cc} \cdot c_c + 0.6 \cdot a_{cc} \cdot b_{cc} \cdot H_{cc} \cdot c_r = a_{cc} \cdot b_{cc} \cdot H_{cc} \cdot (c_c + 0.085 \cdot c_r) =$$
$$2.5 \cdot 8.0 \cdot 0.3 \cdot (3500 + 0.085 \cdot 32000) = 37320 \quad \text{RUB}$$

where a_{cc} – width of the conventional slab,

b_{cc} – length of the conventional slab,

H_{cc} – height of the conventional slab.

4. Results and Discussion

In this study properties, sustainability, and cost efficiency are considered in case of appliance in Russia. All prices are given in accordance with Russian construction market.

Bubbledeck technology is popular with different countries. Review of the properties of these slabs was given by A. Churakov in his paper [1]. Advantages and disadvantages of the new technology were considered and compared with currently known methods. Mahmood M.R.K., Dawood W.B. carried out analysis and design of the voided biaxial slab for its application in Kenya [5]. In this paper research of the concrete reduction, and as a result weight reduction are estimated. Suggestions for cost efficiency are presented.

In summary, the bubbledeck is sustainable technology with the wide range of advantages for a construction: namely, absence of beams in the construction, fire safety, lightweight etc. The cost of this technology in Russia would be twice higher as the cost of the conventional concrete. But it should be said, that the manufacturing and transportation costs were not taken into account as well as the price of formwork for the conventional concrete, and time production. However, it is widely known these parameters have great impact on construction as researches [16-18] show.

5. Conclusion

Possibility estimation and efficiency of appliance the Bubbledeck technology in Russia were conducted. Several conclusions were made.

1. Using of the bubbledeck may decrease the overall weight of the structure without affecting carrying capacity, therefore, this technology can reduce foundations efforts and decrease the costs. Sustainability of this technology is quite well: it is certified by LEED and may save around 35% of the concrete. Also, it is possible to save around 40 kg of CO^2 emission in 1 m² of construction. Furthermore, the plastic of the bubbles can be recycled. Biaxial voided slabs are environmentally friendly technology owing to the elimination of the wood use, decrease of the construction waste, and decrease of the concrete use that means reducing the number of transportation and energy consumption.

2. The cost of the Bubbledeck slab technology at Russian construction market would be higher than the cost of the conventional concrete in around 2 times. Estimation was made only for materials without considering workforce number, formwork using, manufacturing and transportation costs. In addition, production time was not taken into account. For more detail estimation all of these parameters should be noted. Most probably, in this case using of the bubbledeck technology would be quite efficient.
3. The Bubbledeck technology is commercially viable for appliance in Russia. This type of the construction does not need special labor or climate conditions. It is necessary to define partner companies who are able to manufacture the plastic PE2NT22 12 bubbles.

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Эффективность применения экологически устойчивой технологии пустотных бетонных плит с пластиковым заполнителем в России

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ИСТОРИЯ

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КЛЮЧЕВЫЕ СЛОВА

пластиковый заполнитель;
расчет стоимости;
пустотная плита;
надежность;
технология строительства;
эффективность применения;

АННОТАЦИЯ

Идея оптимизации использования бетона, а именно уменьшение количества материала и внедрение новых технологий, не является новой. За последние три десятилетия несколько проектов и исследований были выполнены с применением пустотных бетонных плит. Пустотная бетонная плита с пластиковым заполнителем состоит из пустотной плиты и пластиковых шаров, которые служат для уменьшения общего объема бетона. В данной статье рассматривается возможность применения данной технологии на Российском рынке. Приводится оценка эффективности использования технологии в сравнении с использованием традиционных методов строительства и материалов. Также приводится сравнением стоимости материалов, необходимых для конструкции плиты с использованием технологии пустотных плит с пластиковым заполнителем и для плиты из бетона. На основании проведенных исследований предлагаются варианты эффективного внедрения и использования технологии в России.

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