ISSN: 2754-4982

Journal of Civil Engineering Research & Technology

SCIENTIFIC Research and Community

Review Article

Open Access

A Comparative with the Massive Slab Constructive System

Túlio Henrique De Oliveira

Bachelor's degree in Civil Engineering, University Centre of Formiga, Brazil

ABSTRACT

In view of the need for the implementation of new slab construction typologies, this study analyzed the feasibility of inserting BD230, BD285 and BD340 bubbledeck slabs with comparative materials used in the usual thickness of 10, 15 and 20 cm by CypeCAD software, and analyze the cost of implementation through cost compositions provided by SINAPI. The place chosen for the case study of this work was the municipality of Formiga, located in the west of Minas Gerais, Brazil in a slab with 241, 8m² surface. When checking the amount of inputs used, it was noted that in the bubbledeck system were superior to conventional slabs, besides the cost being higher, consequently making the implementation of this technology in this type of work.

***Corresponding author**

Túlio Henrique De Oliveira, Bachelor's degree in Civil Engineering, University Centre of Formiga, Brazil. E-Mail: tulio4.henriqq@gmail.com

Received: March 05, 2021; **Accepted:** March 15, 2021; **Published:** March 20, 2021

Keywords: Bubbledeck. Slabs. Concrete

Introduction

In civil construction, the slab is an essential structural element to allow multiple floors and serve as a cover. The volume of concrete used makes the structures robust, in addition to not contributing to the environment, and there is a need to create new techniques that reduce their use. According to Sketcher et al. (2010), to optimize the consumption of concrete used in structures, the first biaxial hollow slab (now known as bubbledeck) was created in the 90s by the Danish engineer Jorgen Brueding, which consists of the insertion of high density polypropylene spheres in the areas conventional slab that do not play a structural function.

The bubbledeck technique is based on the foundation of being sustainable with the reuse of the polymer used in the constructions, reducing the amount of gas emissions, the amount of materials used, which resulted in the Green Seal award (LEDD certificate - Leaderhip in Energy and Environmental Design) [1]. It is characterized by the insertion of chemically inert hollow spheres, at the intersection of welded or tied screens and fixed in lattice profiles [2]. The distance of the polypropylene spheres must be 1/9 greater than their diameter and the thickness of the slab varies according to the spans to be overcome, according to the type of each project reaching up to 600mm, and can be of type A, B or C, Bubbledeck UK Ltda (2008).

Type A includes the insertion of a lower layer with a thickness of 60mm of concrete and requires a crane to lift such part, since they are not assembled on site and because it is partially concreted, their weight is greater. This type is commonly used in new projects implemented because it is easy to install and is ideal for accommodating pipes and parts of electrical and hydraulic installations, and openings in the slab may be included even after completion. Type B of the bubbledeck system, modules are made and include bubble reinforcement, commonly used in renovations and consists of installing bubbles on the spot, without the need for a mobile or fixed crane, the slab being concreted in two stages, with the need for confection formwork at the bottom as a floor, in addition to being essential in works with a compact construction site. In type C, bubbledeck slabs are assembled outside the construction site and delivered completely filled with their final thickness according to the needs of each project. The big disadvantage this type can be characterized by the coverage of only one direction of the slab, with the planks receiving support beams within the structure or supporting walls such as the precast slab, as stated by Bubbledeck UK ltda (2008).

For calculation purposes, the bubbledeck slab can be defined as a solid slab, using NBR 6118 (ABNT, 2014) as a parameter for dimensioning, disregarding the existing voids due to the presence of bubbles because they do not have a structural function [3]. In Europe, the technical standard DIN 1045 (2001) is used, in addition to the EUROCODE 2 (2004), ACI 318 (2014) and the British standard EM 13747 (2005), specific to the construction technique [4]. In comparison, in view of the conventional system, it was found that the system was deficient in relation to its puncture resistance in the slab-column connections, which could compromise the use of technical standards for smooth slabs and the creation of specific standards, with the need for from the removal of polypropylene bubbles in the connection regions between slab and column and the formation of a solid slab, this area varies according to the loads and the thickness of the concrete used [5].

To confirm the strength of this slab compared to a conventional slab and the fact that it uses the Brazilian standard NBR 6118 (ABNT, 2014) as a dimension for a bubbledeck slab, [5] carried out experiments with six slabs. In this case, three were 24 mm thick and three 45 mm thick, defined according to the predominance of use. The concrete used in the experiment was class 25Mpa and 35Mpa compressive strength and aggregates with a thickness of 16 mm in diameter. Each sample included a support pillar, so that the applied effort was for puncture, located at 8 different points in a circle with a radius of 1125 mm. The samples were subjected to loads until their rupture with the aid of the hydraulic jack and the first impression observed was that the slabs behaved differently to the smooth slabs due to different puncture circles due to the use of bubbles. In fact, when sawing the slab, he detected that the voids significantly interfered with the resistance in the slab-column connections, with an angle of 30 and 40º.

Through experiments using the SAP 2000 computer program (CSI AMERICA, 1961) in three-dimensional dimensions, [15] used samples of solid and bubbledeck slabs for static and dynamic analysis on both slabs. Thus they were subjected to a loading of 4.8KN/m² in addition to their own weight and concludes that the bubbledeck slabs have a behavior lower than the maximum moments, strength shear and stresses in the plane around 30 to 40% compared to solid slabs, due to the use of spheres and reduction of the structure's own weight. In contrast, the displacements of this slab are 10% greater than the solid slabs, due to its less rigidity with the presence of hollow voids in the structure. In the dynamic part, both presented concordant behaviors. [6] researched the fact that Bubbledeck International, (normative company of the system), considered the bubbledeck system with a reduction factor of 40% in comparison with solid slabs to its puncture resistance. In order to evaluate this fact, he describes in a function, the area of a solid slab of the same height as a factor for determining the shear puncture of bubbledeck slabs; and K factor, a relationship between the existing voids and the neutral line. The results obtained were that their mathematical formulations would relate to the modification in which it was foreseen in Bubbledeck International's recommendations.

As in Brazil the technique is still not widespread, few works have been carried out with this method. In such a way, the first work performed was the Administrative Center of Brasília-DF, whose use was defined after evaluating the feasibility of using this system. One of the tests used to evaluate the behavior consisted of loading 2 pools positioned on the 300kgf/m² slabs as a load test performed according to NBR 9607 (ABNT, 2013) - Load test in reinforced concrete structures and prestressed - with slabs 280 mm thick. The result showed no increase or appearance of cracks in the structure [7]. In addition to this experiment, [4] carried out tests that consisted of loading 5 slabs of 2.5mx 2.5m with 280 mm thickness, 4 of which were bubbledeck and one massive with the insertion of shear reinforcement pins (studs) in the ribs of the slab between the connection of the columns and trusses. The pins did not significantly increase the strength of the slabs. On the other hand, the insertion of trusses had contributed to an increase of 30% in comparison to the other slabs. However, the experiment generated overestimated results and the number of tests was not sufficient to obtain concrete results [8].

For dimensioning the bubbledeck system, some parameters are different from solid slabs, such as the self-weight which is reduced by one third in structures of the same thickness, which corresponds to a self-weight 65% less than the smooth slabs; the flexural stiffness is calculated from 0.9 to a solid slab of the same height, and the resistance to cutting as it is proportional to the amount of existing concrete, the system reduces accordingly, about 0.6 to a slab of the same height. In practice, when the cutting effort is greater, the slab-column connection can be considered empty without the insertion of spheres or the greater use of reinforcing steel to the cutting, [13].

In view of all the prescribed information, this study consisted of analyzing the applicability of the bubbledeck constructive technique, comparing it with the conventional system of solid slabs, verifying the resistance in which the two behave with comparisons of the quantities of materials used and the use of concrete in the structure. , in addition to determining the feasibility of using a new bidirectional slab system with voids.

Material and Methods

The bubbledeck technique eases the use in several projects, since it is up to the designer to determine the thickness of the slab, the spans to be reached, since the system is viable in structures with continuous spans. [9]. To determine the type used by the designer the TAB. 1 presents the data of the technique used for sizing.

Table 1: Bubbledeck Data

KIND	SLAB THICKNESS (MM)	BALL DIAMETER (MM)	TOTAL LOAD (kn/m²)	CONCRETE CONSUMPTION (m³/m²)	MAXIMUM SPACES TO BE EXCEEDED (m)
BD230	230	180	4,26	0,15	6 – 9
BD285	285	225	5,11	0,19	7 – 11
BD340	340	270	6,22	0,23	9 – 13
BD395	395	315	6,92	0,25	10 – 15
BD450	450	360	7,95	0,31	11 – 17

Fonte: Bubbledeck Uk (2008).

Through the diameters presented, according to TAB. 2, there are relevant data to design the bubbledeck system, including the insertion of the bubble spacing between axes, the number of spheres per m², load reduction factors, as well as specifications on minimum slab thickness characterizing the permissible structural properties of the system.

Table 2: Properties According To the Diameter of the Sphere

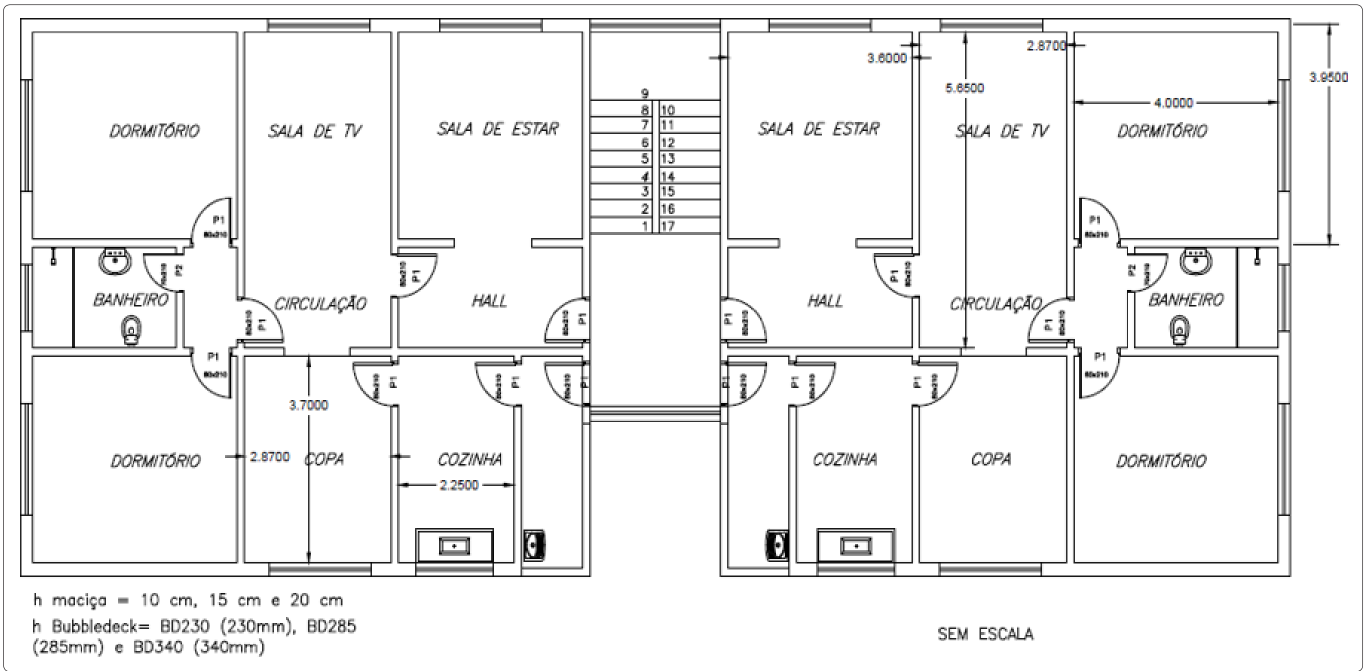
Ball diameter (m)	0,18	0,225	0,27	0,315	0,36	0,405	0,450
Minimum interest of the spheres (m)	0,20	0,25	0,30	0,35	0,40	0,45	0,50
Number of spheres (m²)	25	16	11	8,16	6,25	4,94	4
Minimum slab thickness (m)	0,23	0,28	0,34	0,40	0,45	0,52	0,58
Load reduction per ball (KN)	0,08	0,15	0,26	0,41	0,61	0,87	1,19
Max. Reduction loading (KN/m²)	1,91	2,39	2,86	3,34	3,82	4,29	4,77
Stiffness Factor	0,88	0,87	0,87	0,88	0,87	0,88	0,88
Cutter Factor	0,60	0,60	0,60	0,60	0,60	0,60	0,60
Weight Factor	0,67	0,66	0,66	0,67	0,66	0,67	0,67

Fonte: Bubbledeck International (2019) [14].

With this information it is possible to perform a pre-dimensioning of the height of the slab to be used and the dimension of the spheres used.

Sizing

The case study evaluates the viability of the bubbledeck slab construction system and raises a comparison between the massive slabs of different thickness to the bubbledeck slabs in a concrete area of 241.8m² realized in the city of Formiga-MG whose construction (FIG. 1) it is of the residential type and has two floors, the ground floor being stilts and ceiling height of 3m.



Source: The author, 2019.

For a bubbledeck slab the self-weight is not the same compared to a solid slab of the same thickness, so it is assumed that 65% of the flat slab's own weight is reduced to biaxial hollow slabs [13]. For the calculation of the slab arrows, the dimensioning was different in comparison to the solid slabs using as factor 0.9 EI (elasticity module x moment of inertia). Solid slab and bubbledeck modules were dimensioned, verifying the feasibility of using the system for saving concrete, using formwork for shoring, in addition to the amount of materials used in the work.

In the first stage the experiment consisted of bubbledeck sizing 23cm, 28.5cm and 34 cm (BD230, BD285 and BD340) for study, as they are usual thicknesses for this type. Thus, the resistance used in the three types of slab and the amount of materials are used as a reference for the next calculations. In the second step, the massive slabs were calculated 10cm, 15cm and 20 cm sequentially to evaluate the amount of material used in the smooth slab system and its discrepancy in relation to the bubbledeck system. Different strengths were attributed to the slabs so that there was a need to insert more thicknesses, since the bubbledeck system has the same behavior as the massive slabs. The concrete used was class C-25 and machined. The type of bubbledeck slab used was type B, without the insertion of a lower layer of concrete, to actually evaluate the total strength of the slab, as there is not enough data on the concrete used if they were type A. Type C also did not was used because there is no specific data on the origin of the concrete and steel bars used in the process. The steel used for the structure is CA-50 and CA-60 with lower and upper meshes spaced every 10cm and 15cm consecutively [7]. For solid slabs, according to TAB. 3, the volume of concrete per square meter of slab was calculated following the dimensions mentioned above. The bubbledeck system, the volume of concrete adopted was following the consumption criteria in m³ of concrete per m² of concrete slab, according to Bubbledeck UK Ltda (2008).

Table 3: Comparison of Volume per m² of Slabs

Massive Slabs		Lajes Bubbledeck	
Thickness (m)	Volume (m³)	Kind	Volume (m³)
0,10	0,10	BD230	0,15
0,15	0,15	BD285	0,19
0,20	0,20	BD340	0,23

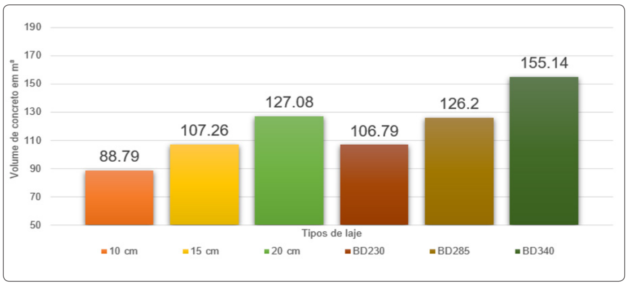
Source: The author, 2019.

The calculation of bubbledeck slabs was performed using the CypeCAD software [10] determining parameters such as resistance, flexion and own weight. In order to exemplify and improve the visualization of information, Excel spreadsheets were also used, in addition to the SINAPI spreadsheet (2019) to determine the costs of the inputs used. The technique is not present in the software, so the system is calculated as a ribbed slab and the information prescribed by the manufacturer is entered for dimensioning [16].

Results and Discussion

About the calculations performed, there is the generation of data on the materials spent on the work, matching the massive and bubbledeck slabs with dimensions as mentioned in the materials and methods. The data provided in accordance with the TAB. 2 show that the volume in m³ of bubbledeck slabs per m² is higher than the massive slabs shown. In such a way, the GRAP. 1 presents information on the quantities of concrete used in m³ according to each type of slabs used for the study.

Graph 1: Quantity of Concrete Used

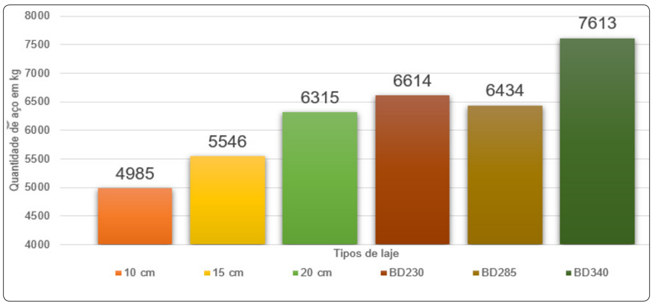


Source: The author, 2019.

It is noted that the amount of concrete in a BD230 type slab (less usual thickness for this technology) is greater than 20.27% compared to a conventional 10cm slab, showing that the spaces between one sphere and another and the solid ones inserted for structure shear is sufficient to overcome the massive slab. There is a smaller discrepancy when considering the second type of slab mentioned, about 17.66% less than the bubbledeck BD285. The BD340 system has the highest consumption of concrete compared to a 20cm thick slab, about 22.5%, as a result of the usual minimum thicknesses for bubbledeck technology.

The considerations about the steel used lead to the dimensioning of the lower and upper meshes of the bubbledeck system, in addition to the complementary reinforcement in the capitals and positive and negative reinforcement of the smooth slab system. THE GRAP. 2 lists this amount of steel in kg used in the six types of slabs mentioned.

Graph 2: Comparison of the Amount of Steel in Smooth and Bubbledeck Slabs

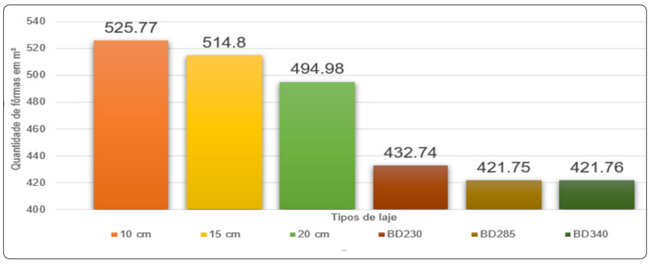


Source: The author, 2019.

The capitals present in the pillars of the bubbledeck structures succeed in the superior design of connecting bars for resistance to shear and puncture of the structure. The lower and upper reinforcements made of meshes spaced every 10cm and 15cm consecutively, reveal greater use of steel in these regions. About 32.68% of steel is saved in 10cm thick slabs compared to a BD230, 16% in 15cm slabs at BD285 and 20.55% in 20 cm thick slabs compared to BD340.

The dimensioning of formwork can be defined by the fact that the system of solid slabs uses panels for beams and floor formwork to ensure that the structure remains intact until its launch and after the concrete has cured. The bubbledeck system eliminates these requirements, consequently the GRAP. 3 demonstrates in m² the economy of formwork used in both types of slab used.

Graph 3: Comparison of Forms Used



Source: The author, 2019.

There is a discrepancy in the values obtained, emphasizing that 21.5% of the forms used in a 230mm bubbledeck slab are saved in relation to the same concrete surface with a solid 10 cm slab, 22.05% in BD285 slabs with slabs of 15cm and 17.36% when comparing a BD340 with a 20cm flat slab.

It is noted that the amount of concrete used in all structures is proportional to the amount of steel used in them, since the weight itself increases and consequently to remain static, the amount of these inputs is increased. On the other hand, the amount of formwork used decreases thanks to the structure supporting greater spans added by increasing the thickness dimension.

When analyzing the consumption of materials used, there are parameters to cover the value per m² of slab used, excluding labor and machinery. TAB. 4 and 5 show the cost of a bubbledeck slab per m² of 230 mm taking as a reference the materials used according to [11] and the cost of a massive 10 cm thick slab. The cost of bubbles is R$ 24.50 per m², [12].

Table 4: Bubbledeck Slab Costs Per m² Type BD230

Materials	Cost	Consumption
steel CA-50 ø6.3mm (kg/m²)	R$ 5,22	6614
Machined concrete includes pump 25Mpa (m³/m²)	R$290,74	106,79
Shapes (m²/m²)	R$20,66	432,74
Spheres (unity)	R$0,87	8315
	Total cost:	R$81747,66
	Cost Per m²:	R$169,23

Source: The author, 2019.

Table 5: Costs of Solid Slab 10cm per m²

Materials	Cost	Consumption
Steel CA-50 ø6.3mm (kg/m²)	R$ 5,22	4985
Machined concrete includes pump 25Mpa (m³/m²)	R$290,74	88,79
Shapes (m²/m²)	R$20,66	525,77
	Total cost:	R$62698,91
	Cost Per m²:	R$129,80

Source: The author, 2019.

The cost of the BD230 bubbledeck slab is R$ 169.23 per m² of constructed slab, while the conventional 10 cm slab is R$ 129.80. This is done by inserting polypropylene spheres into the structure, the amount of steel required in the Danish type and the consumption of concrete. For the BD285 and the 15cm solid slab, according to the TAB. 6 and 7 show the costs of the inputs used to manufacture both in constructed m².

Table 6: Costs of Solid Slab 15cm per m²

Materials	Cost	Consumption
Steel CA-50 ø6.3mm (kg/m²)	R$ 5,22	5546
Machined concrete includes pump 25Mpa (m³/m²)	R$290,74	107,26
Shapes (m²/m²)	R$20,66	514,8
	Total cost:	R$70770,66
	Cost Per m²:	R$146,51

Source: The author, 2019.

Table 7: Costs of BD285 Bubbledeck Slabs per m²

Materials	Cost	Consumption
Steel CA-50 ø6.3mm (kg/m²)	R$ 5,22	5546
Machined concrete includes pump 25Mpa (m³/m²)	R$290,74	107,26
Shapes (m²/m²)	R$20,66	514,8
	Total cost:	R$70770,66
	Cost Per m²:	R$146,51

Source: The author, 2019.

The consumption of superior materials in BD285 slabs compared to a 15 cm slab raises its purchase value by R$ 26.14. For spans up to 11m in length where the project does not present and does not consent with the insertion of beams and columns, the BD285 bubbledeck system lives up to this process, even if it costs a little more than the conventional system. Finally, slabs of the BD340 type are presented and their costs compared to smooth slabs with a thickness of 20cm in m² of concrete surface, according to the TAB. 8 and 9.

Table 8: Bubbledeck Slab Costs Per m² Type BD340

Materials	Cost	Consumption
Steel CA-50 ø6.3mm (kg/m²)	R$ 5,22	7613
Machined concrete includes pump 25Mpa (m³/m²)	R$290,74	155,14
Shapes (m²/m²)	R$20,66	421,76
Spheres (unity)	R$0,87	2697
	Total cost:	R$95905,21
	Cost Per m²:	R$198,55

Source: The author, 2019.

Table 9: Costs of Massive Slab 20cm

Materials	Cost	Consumption
Steel CA-50 ø6.3mm (kg/m²)	R$ 5,22	6315
Machined concrete includes pump 25Mpa (m³/m²)	R$290,74	127,08
Shapes (m²/m²)	R$20,66	494,98
	Total cost:	R$801237,82
	Cost Per m²:	R$165,90

Source: The author, 2019.

The values obtained, demonstrate a high cost in adopting the new Danish technology, in addition to the cost to obtain such parts and that make possible the use in the current works as well as the amount of materials used, but it is worth stating that its use becomes feasible, since that the site has such methods and labor costs to adopt such a method are analyzed.

Conclusions

Based on the data provided and on the literature presented on the bubbledeck system, its use in small structures like the one mentioned in this work is not feasible. It is worth mentioning the savings in materials when there are large spans to be overcome and in works that have difficulties in transporting machinery. One of the advantages used in the system is the savings in used plastics and lower CO2 emissions. However, as proven, the minimum thicknesses of solid slabs are still at an advantage due to the fact that they have less weight of their own and, consequently, a smaller amount of concrete. Even with the insertion of beams in the structure and the greater expense of wood for making shapes, massive slabs become cheaper. In fact, the bubbledeck system only proves why it has not expanded all over the world, since its specifications follow the same as the standards for solid slabs, the fear and the price make it necessary to evaluate the details of the project to execute works with such a technique. Thus, new technologies are of paramount importance for civil construction, but it is worth analyzing their particularities when adopting a new system that is economically relevant and meets the projected needs. In view of the above, it is worth mentioning that, in none of the cases analyzing the bubbledeck system with massive slabs, the implementation of the new technique was feasible taking into account the amount of concrete used. The economy of concrete used in bubbledeck slabs is only significant when compared to slabs of the same thickness, as with the types used for the experiment, the amount of concrete used was higher in all cases.

Acknowledgments
To my advisor Tiago and Kildren Oliveira from the city of Piumhi-MG who opened his office on Saturdays to assist me in the development of this article, and of course, to Bubbledeck Brasil who sent me all the material used in the research.

References

1. LIMA, Henrique Jorge Nery (2015) Experimental analysis on the punching of smooth slabs BubbleDeck. Federal District.
2. Sergiu Călin, Ciprian Asăvoaie (2009) Method for bubbledeck concrete slab with gaps. Flight. LV (LIX) 2: 63-70.
3. Sergiu Călin, Roxana Gînțu, G Dascalu (2009) Sumary of tests and studies done abroad on the bubble deck system. Department of Concrete, Technology and Organization, 2009.
4. Ceballos, Manuel Alejandro (2017) Experimental analysis of puncture in Bubbledeck slabs with shear reinforcement. Federal District, Brasilia.
5. MartinaSchnellenbach-Held, KarstenPfeffer (2002) Punching behavior of biaxial hollow slabs. Cement and Concrete Composites 24: 551-556.
6. Aldejohann M (2008) Zum querkrafttragverhalten von hohlkörperdecken mit zweiachsiger lastabtragung. Doctoral thesis. Universität Duisburg Essen, Germany p185.
7. Bubbledeck Brasil (2019) Available at: http://www.bubbledeck.com.br/.
8. Nicácio, Wanderley Gustavo (2018) Punching behavior of bubbledeck reinforced concrete slabs, Brasília.
9. Andrade, Ramon Lauton, Guedes, Niara Dias (2015) Performance evaluation of structures using bubbledeck slabs. Brasília: Universidade De Brasília, 2015.106 f. Monograph of the civil engineering course. Brasilia.
10. Cypecad (2019) Software for Structural Calculations. Version 2019.a. [S. l.]: Multiplus Softwares Técnicos, Software.
11. Zanchin, Rayssa, Fernandes, Mariana dos Santos (2019) Slab constructions with the bubbledeck system. São Paulo: Complexo Educacional FMU, 2019. Revista Inovae 7: 186-200.
12. Fernandes, Ossimar Júnior Duarte (2014) Bubbledeck slabs - general characteristics and executive viability. Goiás: IPOG, 2014. MBA in construction management, technology and construction quality, Postgraduate Institute, Goiânia, Goiás.
13. Bubbledeck UK LTDA (2019) Available at: http://www.bubbledeck-uk.com.
14. International, Bubbledeck (2019) Calculations. Available in: www.bubbledeck.com.
15. Lai T (2010) Structural Behavior of BubbleDeck Slabs And Their Application to Lightweight Bridge Decks. Cambridge, USA.
16. Sinapi MG- Civil Construction Indexes. Available in: http://www.caixa.gov.br/site/Paginas/downloads.aspx#categoria_648.