



HOKKAIDO UNIVERSITY

Title	THE EXPERIMENTAL ANALYSIS OF BUBBLEDECK SLAB USING MODIFIED ELLIPTICAL BALLS
Author(s)	HAI, L. V.; HUNG, V. D.; THI, T. M. et al.
Description	The Thirteenth East Asia-Pacific Conference on Structural Engineering and Construction (EASEC-13), September 11-13, 2013, Sapporo, Japan.
Relation	Proceedings of the Thirteenth East Asia-Pacific Conference on Structural Engineering and Construction (EASEC-13), September 11-13, 2013, Sapporo, Japan, G-6-1.
Citation	Proceedings of the Thirteenth East Asia-Pacific Conference on Structural Engineering and Construction (EASEC-13), G-6-1
Issue Date	2013-09-13
Doc URL	https://hdl.handle.net/2115/54436
Type	conference paper
File Information	easec13-G-6-1.pdf



THE EXPERIMENTAL ANALYSIS OF BUBBLEDECK SLAB USING MODIFIED ELLIPTICAL BALLS

L. V. HAI^{1*}, V. D. HUNG¹, T. M. THI², T. NGUYEN-THOI³, and N. T. PHUOC¹

¹ *Department of Civil Engineering, Ho Chi Minh City University of Technology, Vietnam National University - Ho Chi Minh, Vietnam*

² *Department of Mechanics, Faculty of Mathematics & Computer Science, University of Science, Vietnam National University - Ho Chi Minh, Vietnam*

³ *Department of Civil and Environmental Engineering, National University of Singapore, Singapore*

ABSTRACT

The new prefabricated construction technology using BubbleDeck slab is recently applied in many industrial projects in the world. BubbleDeck slab uses hollow spherical balls made by recycled plastic and therefore it is an innovatory method of virtually eliminating the concrete part in the middle of conventional slab which does not contribute to the structural performance. This hence reduces significantly the structural selfweight. In this paper, the experimental results of BubbleDeck slab subjected to static loadings are presented. The effects of various factors to the behaviors of BubbleDeck slab are considered, such as the concrete strength, the shape and diameter of plastic balls, the size of reinforcing mesh at top and bottom. In order to demonstrate the superiority and advances of the mentioned technology, the improving of the plastic ball's shape by using hollow elliptical balls for better load-bearing capacity in BubbleDeck is also presented in details. The research results show the effectiveness and feasibility of the application of BubbleDeck in the construction works in Ho Chi Minh City, Vietnam.

Keywords: BubbleDeck, Hollow spherical balls, Hollow elliptical balls, ANSYS.

1. INTRODUCTION

The BubbleDeck slab is a revolutionary biaxial concrete floor system developed in Europe in 1990's by Jorgen Breuning (BubbleDeck-UK 2008). The traditional BubbleDeck technology uses spheres made of recycled industrial plastic to create air voids while providing strength through arch action. This results in a dramatic reduction of dead weight by as much as 50% allowing much longer spans and less supporting structure than traditional solutions. Therefore, the BubbleDeck has

* Corresponding author: Email: lvhai@hcmut.edu.vn

† Presenter: Email: lvhai@hcmut.edu.vn

many advantages as compare to traditional concrete slab, such as: lower total cost, reduced material use, enhanced structural efficiency, decreased construction time, and is a green technology. It gains much of attention from engineers and researchers from the world. For examples, Paul (2004) reviewed the significant highlights of the BubbleDeck and recommended this novel structure to contractors. Marais et al. (2010) investigated the economical value of internal spherical void formers (SVF) slabs in South Africa and compared the direct construction cost to those of two other large span slab systems, namely coffer and post-tensioned slabs. They concluded that the stiffness of SVF slab areas should be reduced by approximately 10% compared to that a solid slab with same thickness. Tina (2010) analyzed the structural behaviors of BubbleDeck slabs and suggested the application to lightweight bridge decks. Calin and Asavaoie (2010) presented the experimental program which refers to concrete slabs with spherical gaps and implied the realization of a monolithic slab element at a scale of 1:1. The results showed the deformation, cracking and failing characteristics of slabs subjected to static gravitational loadings. Unfortunately, all aforementioned studies are related to the study of BubbleDeck using only hollow spherical balls, e.g. no other shapes of balls have been found.

This paper mainly focuses on the experimental results of BubbleDeck subjected to static loadings. The effects of concrete strength, the shape and diameter of plastic balls will be considered to the overall behaviors of BubbleDeck. The improving of the traditional spherical ball's shape by using hollow elliptical balls for better load-bearing capacity in BubbleDeck will be investigated. In order to demonstrate the advances of mentioned technology, the comparison of ultimate loading and maximum deflection at the center of BubbleDeck between experiments and finite element modeling using ANSYS will be carried out.

2. THE BENDING AND SHEAR CAPACITY OF BUBBLEDECK USING TCXDVN 2005

At present, the Vietnamese Construction Building Codes (TCXDVN) have not been updated for the calculation of BubbleDeck. Therefore, the modified TCXDVN 356-2005 Vietnamese code is introduced in this paper to cover for the investigation of BubbleDeck. Base on this modified code, the formulation and equation of BubbleDeck using hollow spherical and elliptical balls are given by using an assumption of T-section as shown in Figure 1.

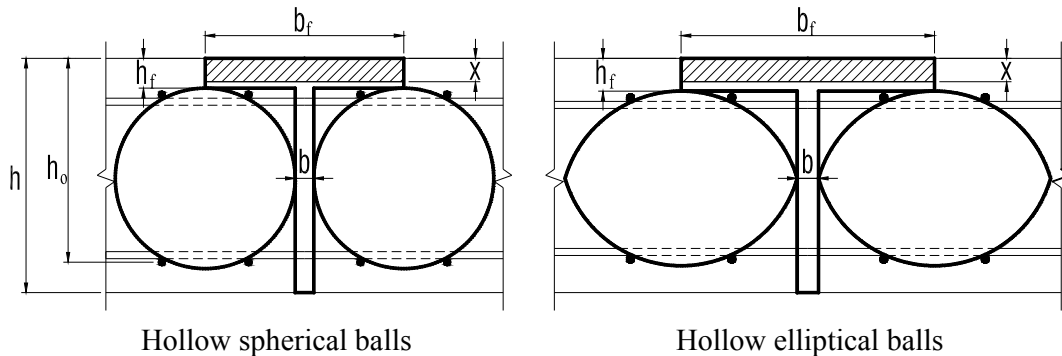


Figure 1: T-section of BubbleDeck using hollow spherical and elliptical balls

2.1. The bending capacity of BubbleDeck using modified TCXDVN 356 - 2005

Based on the assumption of T-section, the ultimate design moment M_{gh} of the section can be given by:

$$M_{gh} = R_s A_s \gamma h_o \quad (1)$$

where R_s is the characteristic yield strength of reinforcement; A_s is the cross-sectional area of tension reinforcement and h_o is effective depth.

When the neutral axis lies within the flange, the neutral axis depth x is determined by:

$$x = \frac{R_s A_s - R_{sc} A'_s}{R_b b_f} \quad (2)$$

where R_b is the characteristic strength of concrete; R_{sc} is the characteristic yield strength of links; A'_s is the cross-sectional area of compression reinforcement; b_f is width of the flange.

In addition, the values of ξ and γ can be obtained when $x < h_f$:

$$\xi = \frac{x}{h_o} \quad (3)$$

$$\gamma = 1 - 0.5\xi \quad (4)$$

When the neutral axis lies within the web, e.g. $x > h_f$, the neutral axis depth x is given by:

$$x = \frac{R_s A_s - R_b (b_f - b) h_f - R_{sc} A'_s}{R_b b} \quad (5)$$

2.2. The shear capacity of BubbleDeck using modified TCXDVN 356 - 2005

The shear capacity of the BubbleDeck can be calculated by using following equations:

$$Q \leq Q_b + Q_{sw} \quad (6)$$

where Q_b and Q_{sw} are the shear resistance of concrete and links, respectively. The shear resistance of links Q_{sw} can be expressed as:

$$Q_{sw} = \sum R_{sw} A_{sw} \quad (7)$$

The shear resistance of concrete Q_b can be obtained from following equations:

$$Q_b = \frac{M_b}{C} \quad (8)$$

where C is the overall length of oblique projection of links and M_b is given by:

$$M_b = \varphi_{b2}(1 + \varphi_f + \varphi_n)R_{bt}bh_o^2 \quad (9)$$

in which φ_{b2} , φ_f and φ_n are factors depend on the concrete type, the compression capacity in T-section and compression capacity of axial force, respectively; b is width of the web and h_o is effective depth.

3. THE EXPERIMENTAL PROGRAM

In order to investigate the behaviors of BubbleDeck using traditional spherical balls and modified elliptical balls, the experimental program were carried out at Laboratory of Full-Scale Structural Testing, Faculty of Civil Engineering, Ho Chi Minh City University of Technology from June 2012 to Sep 2012.

3.1. BubbleDeck samples

Advanced engineering of the BubbleDeck system comprises a hollow flat slab, into which recycled plastic ball ‘void formers’ are incorporated to eliminate concrete that does not contribute to the structural performance a slab. The plastic balls have dimensions and shapes as follows: hollow spherical balls with diameter 186mm and hollow elliptical balls with diameter 240mm and height 180mm as shown in Figure 2.

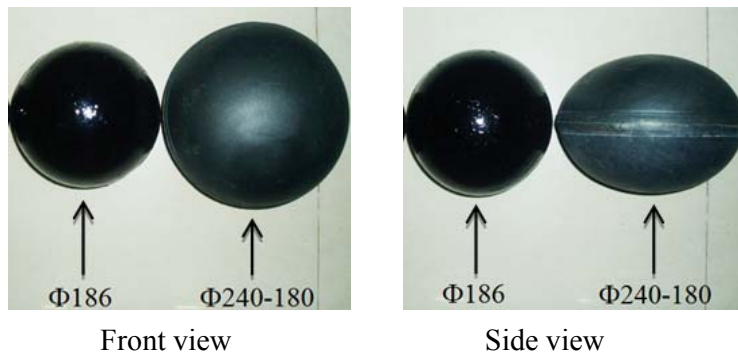


Figure 2: Shape and dimension of plastic balls.

There are total 5 BubbleDeck samples named as A.BD.2, A.BD.3, A.BD.4, B.BD.2 and B.BD.3. All samples have the same dimension of 1900x800x230 mm. The notations A and B denote for the concrete strength B25 and B35, respectively. Table 1 depicts the dimension and notation of BubbleDeck samples. It should be mentioned that only the sample A.BD4 has been provided the links and other samples do not have links.

Figure 3 demonstrates the plan view and sections of modified BubbleDeck using hollow elliptical balls. There have total 18 elliptical balls for 1 BubbleDeck sample. The reinforcing rebar at the top

and bottom layers is $24\Phi 8$ and the concrete cover is 25mm. Figure 4 shows the actual BubbleDeck samples in the laboratory.

Table 1: Dimension and notation of BubbleDeck samples

Slab	Concrete strength	Dimension 1900x800x230 mm		
		BD $\Phi 186$ (no links)	BD $\Phi 240-180$ (no links)	BD $\Phi 240-180$ (have links)
Notation	A	B25	A.BD.2	A.BD.3
	B	B35	B.BD.2	B.BD.3

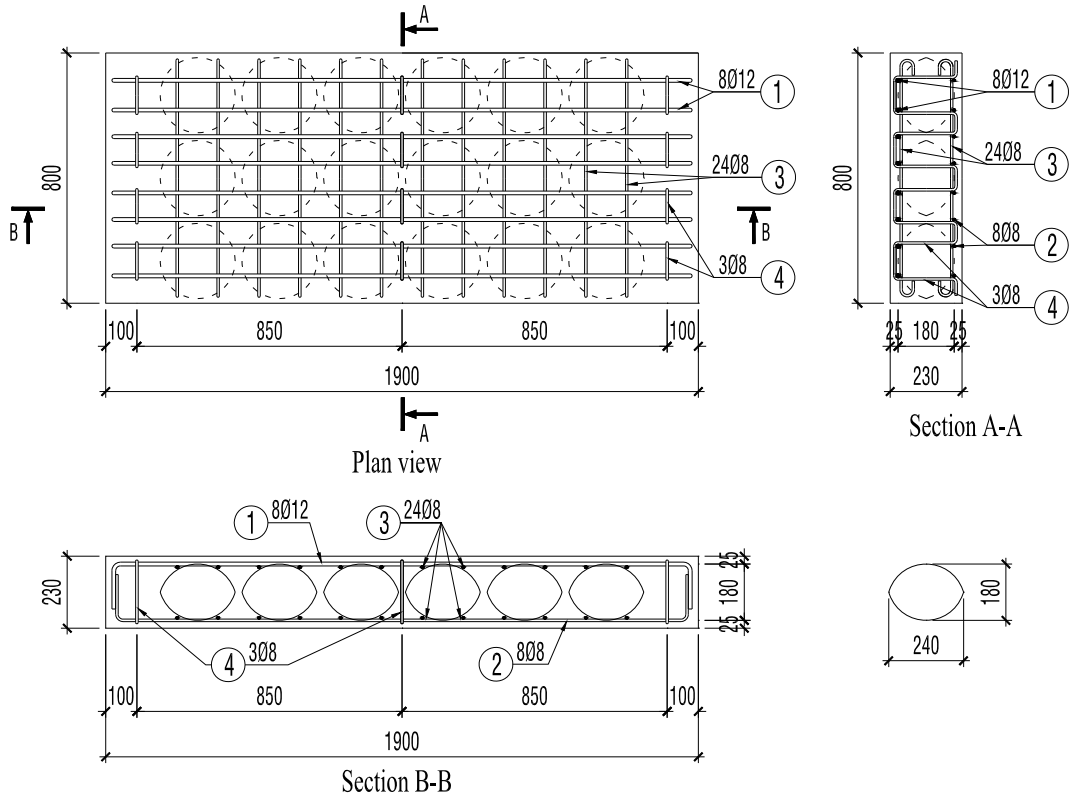


Figure 3: Modified BubbleDeck A.BD.3 và B.BD.3.



Hollow spherical balls

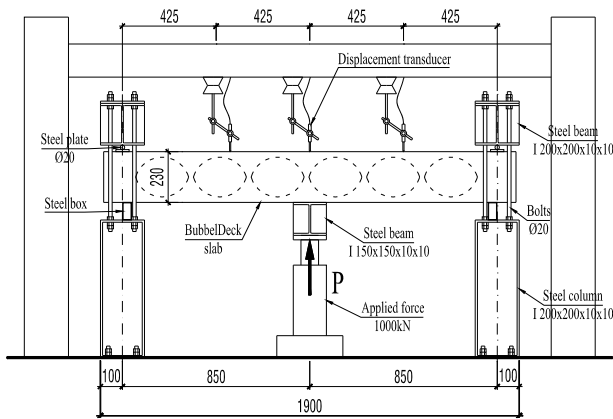


Hollow elliptical balls

Figure 4: BubbleDeck samples.

3.2. Experimental procedure

Figure 5 gives the modeling and actualization of experimental setup. The BubbleDeck samples are simply supported by two steel beams I200x200x10x10 along the short span. The applied force at the center of slabs is produced by the hydraulic jack with the capacity of maximum loading 1000kN. Initially, the hydraulic jack is adjusted with the force same as the selfweight of the slab. In this experiment, the applied force is provided from the bottom to the top of the slab, which is opposite to the direction of gravity. By applying this procedure, it is easier for us to record the strain and deformation of concrete and rebar from the top side of the slab. It should be noted that the strain and deformation of concrete and rebar are measured by using the wire strain gauge as shown in Figure 6. Next, the applied force will be increased step by step until the cracks are found in the slabs and the failure modes are appeared.



Modelling of experimental setup



Actualization of experimental setup

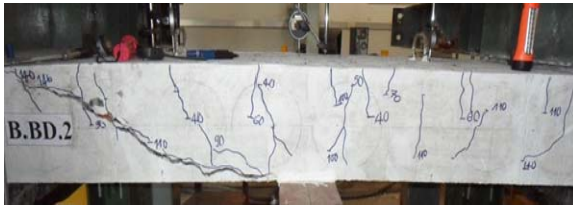
Figure 5: Experimental setup.



Figure 6: Wire strain gauge.

3.3. Experimental results

Figure 7 shows the observed crack patterns at failure for the slab B.BD.2 and B.BD.3. It can be seen from this figure that failure modes of slabs B.BD.2 and B.BD.3 are shear and bending modes, respectively. In details, Table 2 demonstrates the ultimate loading, maximum deflection at the center and type of failure of all slabs. It should be noted that the BubbleDeck using hollow spherical balls A.BD.2 and B.BD.2 has the shear failure modes. On contrary, the BubbleDeck using modified elliptical balls A.BD.3, A.BD.4 and B.BD.3 has the bending failure modes. It can be concluded that with the same dimension and concrete grade, the BubbleDeck using modified elliptical balls has greater ultimate loading than that using hollow spherical balls.



The shear failure of slab B.BD.2



The bending failure of slab B.BD.3

Figure 7: The failure modes of BubbleDeck.

Figure 8 shows the relationship between ultimate loading P and the maximum deflection at the center of BubbleDeck. The figure is plotted for two types of concrete strength, e.g. B25 (type A) and B35 (type B), and for different types of BubbleDeck. It can be observed from this figure that the maximum deflection at the center of slabs is increased when the applied loading is increased. More details, Table 3 depicts the results of ultimate loading and center deflection of all types of BubbleDeck. It can be seen from this table that the loading capacity of BubbleDeck using concrete grade B35 is higher from 3% to 8% as compare to that of BubbleDeck using concrete grade B25. By using the modified BubbleDeck with hollow elliptical balls $\Phi 240-180$, the loading capacity is increased from 6% to 11% as compare to that of traditional BubbleDeck with hollow spherical balls $\Phi 186$. In addition, the experimental results also show that the modified BubbleDeck with hollow elliptical balls $\Phi 240-180$ has better shearing capacity as compare to the BubbleDeck with hollow spherical balls $\Phi 186$. The loading capacity is increased approximately 6% by using the links in BubbleDeck, e.g. the links has not much contribution to the capacity of the slabs.

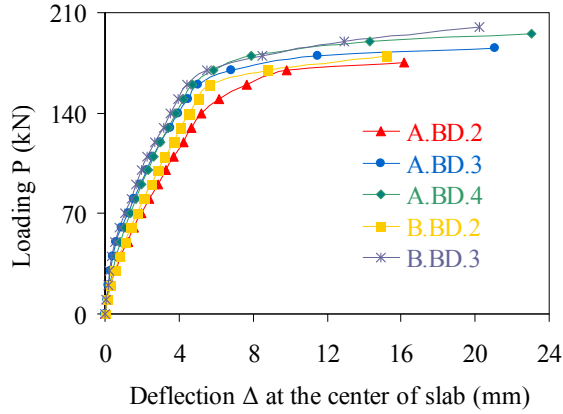


Table 2: Experimental results

Slab	Ultimate loading P_u (kN)	Deflection Δ_u (mm)	Type of failure
A.BD.2	175	16.15	Shear
A.BD.3	185	21.06	Bending
A.BD.4	195	23.04	Bending
B.BD.2	180	15.18	Shear
B.BD.3	200	20.22	Bending

Figure 8: Load – deflection of BubbleDeck.

Table 3: Comparison of ultimate loading and center deflection of BubbleDeck

Slab	Ultimate loading P_u (kN)		Error (%)	Deflection Δ_u (mm)		Error (%)
A (B25)	A.BD.2	A.BD.3	5.7	A.BD.2	A.BD.3	30.4
	175	185		16.15	21.06	
B (B35)	B.BD.2	B.BD.3	11.1	B.BD.2	B.BD.3	33.2
	180	200		15.18	20.22	
BD Φ 186	A.BD.2	B.BD.2	2.9	A.BD.2	B.BD.2	-6.0
	175	180		16.15	15.18	
BD Φ 240-180	A.BD.3	B.BD.3	8.1	A.BD.3	B.BD.3	-4.0
	185	200		21.06	20.22	
BD Φ 240-180 (Links and no links)	A.BD.3	A.BD.4	5.4	A.BD.3	A.BD.4	9.4
	185	195		21.06	23.04	

4. BUBBLEDECK USING FINITE ELEMENT METHOD

In order to analyze the BubbleDeck using traditional finite element method, the discrete model in ANSYS as shown in Figure 9 is proposed (Anh & Loan 2011).

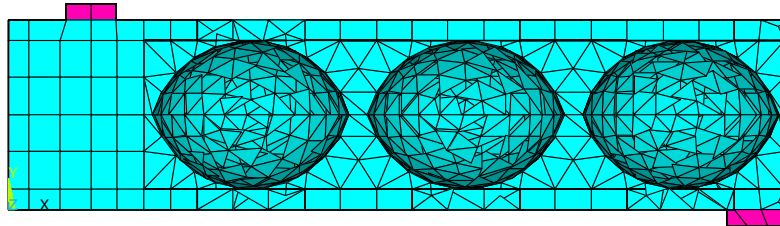


Figure 9: Modelling and meshing of BubbleDeck using hollow elliptical balls.

Table 4 depicts the comparison of ultimate loading and deflection at the center of BubbleDeck between experiments and ANSYS. The maximum error between two models is found to be approximately 17%. This value can be acceptable and it could be explained that the main reason may come from the ANSYS software which does not consider for the interaction between the

concrete materials, steel rebar and the recycled plastic balls. The errors may also due to the experimental procedure (recording loading, train and deformation; the actual concrete and steel strength; the experimental setup...).

Table 4: Comparison of ultimate loading and deflection between experiment and ANSYS

Slab	Ultimate loading P_u (kN)			Deflection Δ_u (mm)		
	Experiment	ANSYS	Error (%)	Experiment	ANSYS	Error (%)
A.BD.2	175	199.2	13.8	16.2	13.5	-16.4
A.BD.3	185	209.0	13.0	21.1	18.9	-10.3
A.BD.4	195	222.1	13.9	23.0	19.7	-14.5
B.BD.2	180	206.5	14.7	15.2	12.8	-15.7
B.BD.3	200	226.8	13.4	20.2	16.7	-17.4

5. CONCLUSIONS

The behaviors of BubbleDeck using traditional hollow spherical balls and modified hollow elliptical balls were investigated in this paper through the experimental program. The effects of concrete strength, the shape and diameter of plastic balls, the size of reinforcing mesh at top and bottom were presented carefully. The finite element program by using ANSYS was also introduced to make the comparison of the results. It can be concluded that by using the hollow elliptical balls, the better load-bearing capacity in BubbleDeck can be achieved. Therefore, the BubbleDeck presents the promising future of advanced structure engineering and it could be applied effectively in the construction works in Vietnam as well as in other countries.

6. ACKNOWLEDGMENTS

This research is funded by Ho Chi Minh City University of Technology, Vietnam National University Ho Chi Minh City (VNU-HCM) under grant number T-KTXD-2013-56.

REFERENCES

- BubbleDeck-UK (2008). BubbleDeck structure solutions – Product introduction. Part 1, BubbleDeck UK Ltd.
- Calin S, and Asavaoie C (2010). Experimental program regarding “Bubble Deck” concrete slab with spherical gaps, *Intersections/Intersectii*, 4(7)-1, pp. 34-40.
- Marais CC, Robberts JM, and van Rensburg BWJ (2010). Spherical void formers in concrete slabs. *Journal of the South African Institution of Civil Engineering*, 52(2), pp. 2 – 11.
- Paul H (2004). BubbleDeck – Advanced structure engineering. Cornerstone 30, pp. 15-16, BubbleDeck C.I. Ltd.
- TCXDVN 356 (2005). Concrete and reinforced concrete structures – Design standard.
- Tina L (2010). Structural behavior of BubbleDeck slabs and their application to lightweight bridge decks, Master of Engineering in Civil and Environmental Engineering at the Massachusetts Institute of Technology, USA.
- Anh VQ & Loan PT (2011). ANSYS version 10.0 for the structural calculation. Vietnamese Construction publishers.