BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi
Tomul LV (LIX), Fasc. 3, 2009
Secţia
CONSTRUCŢII. ĂRHITECTURĂ

SUMARY OF TESTS AND STUDIES DONE ABROAD ON THE BUBBLE DECK SYSTEM

BY

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Abstract. The procedure Bubble Deck was applied untill now in Europe, in countries like Austria, Belgium, Denmark, Germany, Iceland, Italy, United Kingdom, Holland, also in other continents, in Canada or USA. This constructive system could not be brought into practice in so many projects achieved, only based on fundamental research to prove its validity, therefore tests were made concerning: bending behavior, reaction to shear force, the behavior of mountings, the reaction to fire, the acoustic behavior of these floors and economic analysis.

Key words: Bending strength; deflection behaviour; creep; cost price.

1. Introduction

Tests have been carried out in Denmark, the Netherlands and in Germany. The conclusions are unambiguous: Bubble Deck will distribute the forces in a better way (an absolute optimum) than any other hollow floorstructures. Because of the three-dimensional structure and the gentle graduated force flow, the hollow spheres will have no negative influence and cause no loss of strength. Bubble Deck behaves like a spatial structure – as the only known hollow concrete floor structure. The tests reveal that the shear strength is even higher than presupposed. This indicates a positive influence of the balls. Furthermore, the practical experience shows a positive effect in the process of concreting – the balls cause an effect similar to plastification additives [1], [3].

All tests, statements and engineering experience confirm the obvious fact that Bubble Deck, in any way acts as a solid slab, and therefore will follow the same rules/regulations as a solid deck (with reduced mass), and further, leads to considerable savings [2].

2. Bending Strength and Deflection Behaviour

2.1 Report from the Eindhoven University of Technology – the Netherlands

This work is executed hand in hand with the Technical University of Delft – the Netherlands. Bubble Deck is compared to a solid deck both practically and theoretically. The behaviour is exactly as for a solid deck, both for short- and long-term situations. The results are shown for the deck thickness 230 mm (type 1) and 455 mm (type 2).

2.2 Test Report ("Biegung") from the Technical University of Darmstadt – Germany

The results from practical tests are compared with a theoretic analysis, concluding consistency between theory and practice. The differences in deflections are very small, and explained by a slight difference in stiffness (Table 1).

Table 1

% of a solid slab	Bubble Deck – solid slab		
	Same strength	Same bending stiffness	Same concrete volume
Strength	*100*	105	150 *
Bending stiffness	87	*100*	300
Volume of concrete	66	69	*100*

* On the condition of the same amount of steel. The concrete it self has 220% greater effect. Based on the report, articles have been published in the "Darmstadt Concrete" (Annual Journal on Concrete and Concrete Structures) which summarizes several tests.

3. Shear Strength

The obtained results of a number of practical tests confirm – once again the obvious – that the shear strength depends only on the effective mass of the concrete. For calculating, a factor 0.6 is used on the shear capacity for a solid deck of identical height. This guarantees a large safety margin.

3.1 Report from AEC Consulting Engineers Ltd. (Professor M.P. Nielsen), the Technical University of Denmark [3]

The shear strength as well as punching shear was tested. The tests were carried out on test elements with thickness on 188 mm. The shear capacity was measured for the ratio *a/d* (distance from imposed force to support divided by deck thickness) of 1.4.

a) Shear strength (bending) – the shear capacity is measured to 8% compared to a solid deck.

b) Punching shear – the average shear capacity is measured to 91 % compared to the calculated values of a solid slab.

3.2 Report from A+U Research Institute (Professor Kleinmann), the Eindhoven University of Technology, the Netherlands [5]

A solid slab is compared with two types of Bubble Deck – one with loose girders (type *L*) and one with secured girders (type *V*) – slab thickness of 340 mm. The shear capacity is measured for two ratios of *a/d*. The results were indicated in Table 2.

Table 2

Shear capacity, [% of solid slab]	*a*/*d* = 2,15	*a*/*d* = 3,0
Solid slab	100	100
Bubble Deck, loose girders	91	78 (81)1
Bubble Deck, loose girders	77	

Based on the test report (“Biegung”) from the Technical University of Darmstadt in Germany, *a*/*d* = 3.7. The shear capacity is measured for 72…78% of a similar solid slab.

3.3 Report "Optimizing of Concrete Constructions”, John Munk & Tomas Moerk, the Engineering School in Horsens, Denmark

A solid deck is compared with Bubble Deck – no girders were used (only binding wire) in the samples – slab thickness of 130 mm. The shear capacity is measured for a ratio *a*/*d* of 2.3. The results were indicated in Table 3.

Table 3

Shear capacity, [% of solid slab]	*a*/*d* = 2.3
Solid slab	100
Bubble Deck, no girders	76

4. Punching Shear

4.1 Report from AEC Consulting Engineers Ltd. , Professor M.P. Nielsen, the Technical University of Denmark

The average shear capacity is measured to 91% compared to a solid deck. Tests were conducted with Bubble Deck slabs of 230 and 450 mm, local punching did not occur, the crack pattern was similar to the crack pattern of solid decks. The test results are summarized in the Fig.1.

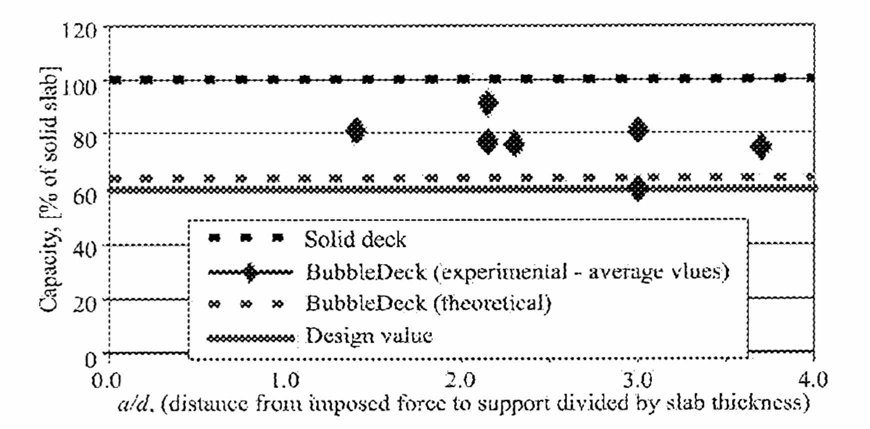

Fig. 1 – Shear capacity.

5. Dynamic Punching Shear

5.1. Report, "Punching Shear Strength of Bubble Deck" by Anders Brønden, Jens Christian Haukohl and Martin Hoft Jørgensen, the Technical University of Denmark

The normalized ultimate load is defined by:

$$\frac{\tau_u}{f_c} = \frac{P}{uhf_c}, \tag{1}$$

where

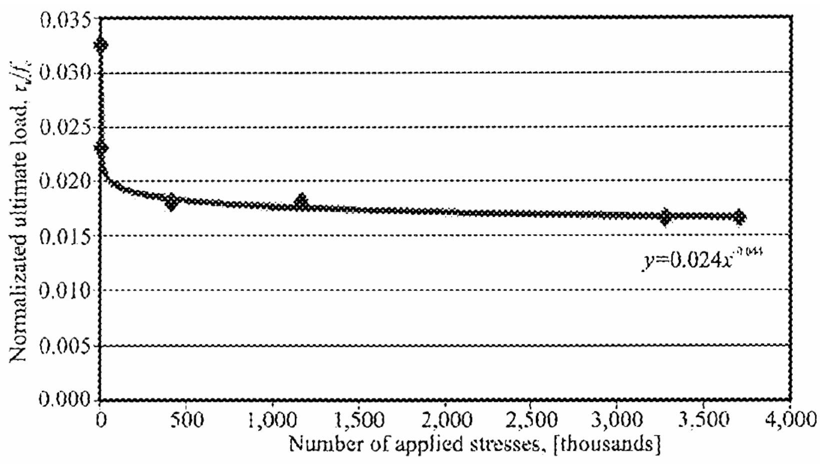

Fig. 2 – Dynamic tests.

(2) $$u = \pi(d + h)$$

is the control perimeter, which used on the experimental results, gives the Wöhler chart represented in Fig 2.

6. Anchoring

6.1. Test Report by Koning & Bienfait b.v., the Netherlands

Three test blocks of Bubble Deck are compared with three test blocks of a solid deck, with same reinforcement, the anchoring in the two types is identical and the balls do not influence the anchoring.

6.2. Report BYG·DTU R-074 2003 by Gudmand-Høyer, Technical University of Denmark [4]

A guidance to calculate the Moment Capacity in a Bubble Deck joint.

7. Fire

7.1 TNO-Report for the Weena Tower , Rotterdam

330 mm deck is fire - safe 60 min with concrete cover 20 mm.

7.2 TNO-Report, 230 mm Deck is Fire-Safe in 120 Min with Concrete Cover 35 mm

TNO is waiting for the CUR-Committee presenting new proposals to concrete regulations considering Bubble Deck. As soon as CUR present their conclusions for Bubble Deck, TNO will change their recommendations.

Until then TNO recommends to follow the present "hollow core" regulations, namely

a) *Separation*: no separation due to fire for at least 120 min.

b) *Bending moment*: satisfactory up to a span of 6.6 m with reinforcement Ø8/Ø10. The span can be increased following an increase in steel dimensions.

c) *Shear stress*: no problems are expected. TNO admits that Bubble Deck is closer to the solid deck than to the "hollow core" deck.

d) A draft calculation over the internal pressure from heated air, heated air imposes no influence (no danger) on the construction.

7.3 German Test Certificate Number P-SAC 02/IV-065 According to DIN 4102-2

The German "Materialforschungs- und Prüfungsanstalt für das Bauwesen Leipzig e.V." has issued the German Test Certificate Number P-SAC 02/IV-065 concerning Fire Resistance according to DIN 4102-2 (in accordance with ISO 834-1).

Design recommendation: the minimum concrete cover of the lower reinforcement as a function of the period and the fire resistance is given in Table 4.

Table 4

Steel stress	Steel utilization, [%]	Fire resistance, [min]				
		30	60	90	120	180
190	66	17 mm	17 mm	17 mm	17 mm	---
286	100	17 mm	29 mm	35 mm	42 mm	55 mm

8. Creep

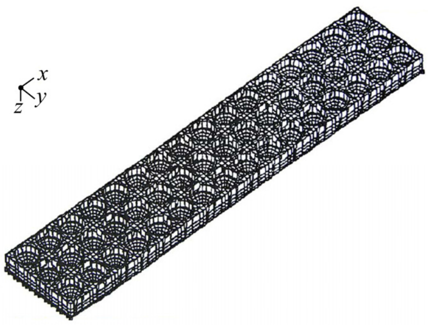

Fig. 3 – 3D-FE model – horizontal cut through a Bubble Deck

8.1 Report from the Eindhoven University of Technology, the Netherlands

No significant difference between Bubble Deck and a solid deck "Darmstadt Concrete" (Annual Journal on Concrete and Concrete Structures). No significant difference between Bubble Deck and solid slab. Differences can be due to the fact that the tests only were considered in a one-way-span (Fig.3).

9. Sound

9.1 Report from Adviesbureau Peutz & Associes in Comparison with Bubble Deck *vs*. Hollow core

A comparison was made between Bubble Deck and hollow core deck *prior* to the construction of Weena Tower, deck types of similar height were compared, the noise reduction with Bubble Deck was 1 dB higher than hollow core. The main criteria for reducing noise is the weight of the deck and therefore Bubble Deck evidently will not act otherwise than other deck types with equal weight.

9.2 German Test Certificate Number P-SAC 02/IV-065 Concerning Solid and Live Load Sound Insulation

The German "Materialforschungs- und Prüfungsanstalt für das Bauwesen Leipzig e.V." has issued the German Test Certificate Number P-SAC 02/IV-065 concerning solid and live load Sound insulation according to DIN EN ISO 140 / DIN ISO 717. The obtained results for 230 and 340 mm decks are given in Table 5.

Table 5

	Sound insulation dimension	Additional spectrum adaptation values (DIN ISO 717-1)						Standard impact sound level
Deck	Rw (C;Ctr)	C50-3150	Ctr50-3150	C50-5000	Ctr50-5000	C100-5000	Ctr100-5000	Lc,w (C1;C50-3150)
mm	dB	dB	dB	dB	dB	dB	dB	dB
230	55 (–2 ; –7)	–2	–8	–1	–10	–1	–8	78 (–11 ; –12)
340	57 (–2 ; –7)	–3	–9	–2	–7	–2	–9	76 (–13 ; –13)

9.3 Test Report from Adviesbureau Peutz & Associes b.v., Sound Resistance, March 2004

Field tests in a raw building in Leiden, the Netherlands, concerning “Air and Contact Noiseresistance”, slabs were BD 230 mm with a fixed floor layer of 30 mm, measurements and ratings were carried out in regulation with ISO 717-1:1996 and NEN 5077:2001 namely:

a) Weighted Sound Reduction (vertical): R'_w (C;Ctr) = 54 (–1; –14).
b) Reduction Index for Airborne Sound: l_{lu} = +3.
c) Impact Resistance Level (vertical): $L'_{n,Tw}$ (C1) = 72 (-14).
d) Reduction Index for Impact Sound: l_{co} = +2.
e) Impact Resistance Level (horizontal): $L'_{n,Tw}$ (C1) = 63 (-13).
f) Reduction Index for Impact Sound: l_{co} = +10.

9.4. Test Report from Ian Sharland Ltd , Airborne and Impact Sound Insulation, November 2005

Field tests in Le Coie Housing Development in St. Helier, Jersey, concerning “Airborne and Impact Sound Insulation”, slabs were BD 285 mm, part of a standard party floor with ceiling and screed, measurements and ratings were carried out in regulation with ISO 140-4:1998, ISO 140-7:1998, ISO 717-1:1997 and ISO 717-2:1997.

a) The Vertical Impact (mean) was measured to: L_{nTw} = 44 dB.
b) The Vertical Airborne (mean) was measured to: D_{nTw} = 59 dB.

The obtained results show that the floor structures tested meet and significantly exceed the requirements of the British Building Regulations (2000).

10. Comparison of Cost Price

10.1. Report from the Eindhoven University of Technology, the Netherlands

In connection with the general tests, a total cost price calculation of the Town Hall in den Haag is carried out. The Town Hall was built with pre-stressed monolithic elements. The complete construction has been evaluated in order to make a reliable comparison.

Two types of comparisons were made:

1. Bubble Deck and a solid deck were compared in three various arrangements – alteration of placement of columns. The calculations were made for increasing spans in the *x*-direction. For a given combination of span and deck thickness, Bubble Deck was 5…16% less expensive than a solid deck. It is important to emphasize that the optimal combination of deck thickness and placement of columns with Bubble Deck differs from a solid deck. A correct comparison must take this fact into consideration, which was made in the second comparison:

2. Two variants of Bubble Deck were compared; the result was clear – the Bubble Deck building was significant less expensive than the traditional system. The total savings was in the order of 20%.

10.2 Report from AEC Consulting Engineers Ltd., Professor M.P. Nielsen, the Technical University of Denmark [3]

Comparisons are made between Bubble Deck and solid slab. Only differences in materials concerning the slabs are considered. Advantages in the building design and building process are not taken into account. For the same amount of steel and concrete, Bubble Deck has 40% larger span and is furthermore 15% cheaper. For the same span, Bubble Deck reduces the amount of concrete with 33%, and reduces the price with 30%.

11. Miscellaneous Savings

Savings can be expected in many respects, in the case of Weena Tower, the experience shows a reduction of 35% in necessary time using the cranes, a very important aspect, especially concerning tall buildings, because of the large amount of downtime due to wind; furthermore, the erection-cycle was reduced from 5 to 4 days per storey. This is confirmed through the following projects where reductions of 1…2 days per storey were obtained. Subsequent works are simplified, savings can also be expected throughout the buildings lifetime due to the high degree of flexibility [6].

12. Approval by Authorities

a) *Dutch Standards* – from November 2001, Bubble Deck is incorporated in the Dutch Standards (by CUR – Civieltechnisch Centrum Uitvoering Research en Regelgeving).

b) *UK Standards* – Bubble Deck can be treated as a normal flat slab supported on columns (BS 8110) according to CRIC (Concrete Research & Innovation Centre under the Imperial College of Science, Technology & Medicine), 1997.

c) *Danish Standards* – Bubble Deck can be calculated from recognized principles and within existing standards – Directorate of Building and Housing, Municipality of Copenhagen, 1996.

d) *German Standards* – Bubble Deck can be used according to existing technical standards according to Deutsches Institut für Bautechnik, 1994.

13. Conclusions

Bubble Deck will distribute the forces in a better way (an absolute optimum) than any other hollow floor structures. Because of the three-dimensional structure and the gentle graduated force flow the hollow areas will have no negative influence and cause no loss of strength. Bubble Deck behaves like a spatial structure – as the only known hollow concrete floor structure, the tests reveal that the shear strength is even higher than presupposed, this indicates a positive influence of the balls. Furthermore, the practical experience shows a positive effect in the process of concreting – the balls cause an effect similar to plastification additives. All tests, statements and engineering experience confirm the obvious fact that Bubble Deck

a) in any way act as a solid deck and consequently

b) will follow the same rules/regulations as a solid deck (with reduced mass), and further

c) leads to considerable savings.

Received, September 11, 2009

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R E F E R E N C E S

1. * * * Agrement Tehnic nr. 007-01/120-2007.
2. * * * Dosarul tehnic al Agrementului Tehnic nr. 007-01/120-2007.
3. Nielsen M.P., *Technical Report AEC Consulting Engineers Ltd.* The Techn. Univ. of Denmark, 2004.
4. Gudmand-Høyer, *Technical Report BYG·DTU R-074 2003*. Techn. Univ. of Denmark, 2004.

5. Kleinmann, *Technical Report from A+U Research Institute.* Technical Report from Eindhoven Univ. of Technol., Netherlands, 2006.
6. * * * www.bubbledeck.com, www.bubbledeck.ro.

SINTEZA TESTELOR ŞI STUDIILOR EFECTUATE ÎN STRĂINĂTATE PE SISTEMUL BUBBLE DECK

(Rezumat)

Procedeul Bubble Deck a fost aplicat până în prezent în Europa, în țări ca: Austria, Belgia, Danemarca, Germania, Islanda, Italia, Marea Britanie, Olanda, dar şi pe alte continente, în Canada sau SUA. Acest sistem constructiv nu ar fi putut fi introdus în practică în numeroasele obiective realizate, decât pe baza unor cercetări fundamentale care să dovedească valabilitatea lui, aşadar s-au făcut teste privind: comportarea la încovoiere, comportarea la forță tăietoare, comportarea sistemelor de prindere, comportarea la foc, comportarea privind acustica acestor planşee şi analize economice.