Bubble Deck Slab System: A Review on the Design and Performance

Zalena Abdul Aziz (Corresponding author)
Lecturer, School of Housing, Building and Planning, Universiti Sains Malaysia,
11800 Penang, Malaysia.
Email: zalena@usm.my

Chan Lek Heng
Postgraduate student, School of Housing, Building and Planning, Universiti Sains Malaysia,
11800 Penang, Malaysia.
Email: chanlekheng@student.usm.my

Abstract

The conventional floor slab has few drawbacks of giving little structural support and posing a large amount of self-weight to a building. Therefore, bubble deck slab system is introduced to tackle these limitations. This paper aims to provide a comprehensive review of the bubble deck slab system on its design and performance. A systematic literature review was conducted in this paper based on the selected journal and articles through the database search engine. The findings will better understand the feasibility of the bubble deck slab system and its potential as a viable replacement for the conventional floor slabs.

Keywords: Bubble deck slab; Biaxial slab; Voided slab; Hollow recycled plastic balls; Reinforced concrete slab

1. Introduction

The Floor slab is part of the essential superstructure elements in a building. However, this conventional slab system is posing a controversy regarding its negative impacts on the environment and its inefficiency by creating little structural support to the building (Berni et al., 2019). The conventional method tends to use more concrete; thus, it increases the dead weight of the building and eventually increases the overall cost of the project (Vinod Kumar et al., 2019). With those issues, many engineers and technologists attempt to implement a new type of floor slab system- bubble deck slab system into the construction industry. In the meantime, it is to increase the awareness of using environmentally-friendly products, as a result, also increase the demand for green building in Malaysia (Lop et al., 2016).

1.1 Bubble Deck Slab System

Figure 1: Bubble deck slab system at the construction site

(Source: BubbleDeck, 2020, Retrieved from https://www.bubbledeck.com/highrisebuildings)

The bubble deck slab system, also known as biaxial hollow slab system, is a reinforced concrete slab which the concrete at the neutral axis of the slab is eliminated and replaced with hollow recycled plastic balls, as a result dramatically reducing in deadweight by 30% compared to the conventional slab system (Lai & Connor, 2010). The system initially was invented by a German professor, Jorgen Bruening in 1990s. Some green attributes including the reduction in total construction materials and costs, lower energy consumption and CO2 emissions that make bubble deck slab system a more sustainable system compared to other concrete construction techniques (A.M. Ibrahim et al., 2019). The technology also helps to eliminate construction waste and severe construction pollution cases in Malaysia (Ahmad Halmi & Ismail, 2017).

Such system has been applied to various building typologies in Malaysia such as residential building, commercial building and industrial building due to the system has various design parameters that could alter to meet the design needs for different projects. The main slab parameters are as below:

Table 1. The parameters of bubble slab system

Type	Slab Thickness. (mm)	Balls diameter (mm)	Span (m)	Mass (kg/m2)	Concrete on-site (m^3/m^2)
BD230	230	Ø 180	7 – 10	370	0.10
BD285	280	Ø 225	8 – 12	460	0.14
BD340	330	Ø 270	9 – 14	550	0.18
BD395	380	Ø 315	10 – 16	640	0.20
BD450	420	Ø 360	11 – 18	730	0.25

(Source: BubbleDeck, 2020, Implementation of Biaxial Hollow Slab System. Retrieved from https://www.bubbledeck.com/services)

1.1.1 Type of Bubble Deck Slab System

Dheepan et al., (2017) and Oukaili & Merie, (2018) has highlighted the different types of bubble deck slab system, which are the Filigree Element, Reinforcement Modules and Finished Planks.

The filigree-slab system is using a semi-precast approach which the slab units are partially prepared in the concrete factory and delivered to the site for completion at a later stage. The bottom side of the 'bubble-lattice' unit is furnished with a 60mm thick precast concrete layer which replaces the horizontal part of the formwork on the building site, acting directly like a seamless ceiling. This method is optimal for the majority of new-build projects.

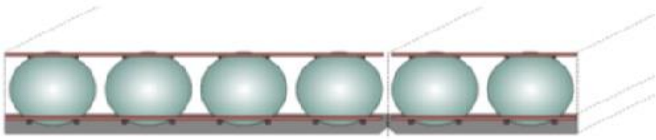


Figure 2: Filigree element slab system

(Source: BubbleDeck, 2020, Retrieved from https://www.bubbledeck.com/highrisebuildings)

The reinforcement module system comprises prefabricated ‘bubble-lattice’ sandwich elements which later are brought to the site and placed on traditional formwork, and then concreted in 2 stages to the full slab depth by conventional methods. This method is suitable for suspended ground floor slabs and alteration or refurbishing projects.

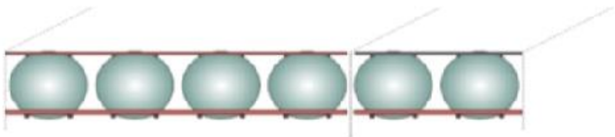


Figure 3: Reinforcement modules system

(Source: Oukaili & Merie, (2018))

The finished planks system is a complete precast element that includes the plastic spheres, reinforcement mesh and concrete in its finished form of a plank. The system is ready to be delivered to the site for installation. This system is often used for shorter spans and tight construction schedules.

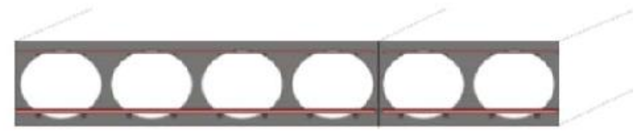


Figure 4: Finished Planks system

(Source: Oukaili & Merie, (2018))

2. Problem Statement

Few important properties to determine the efficiency of a floor slab, the most common properties that have been tested frequently are the load capacity and deflection of the concrete slab. Load capacity is the maximum allowable force that can be applied to the carriage surface (Serge et al., 2016). The deflection defined as the movement of a point on the structural element that is displaced under a load. Previous studies have shown the drawbacks of the bubble deck slab system compared with the conventional solid slab system which it has lower load capacity and higher deflection with the same reinforcement ratio from the solid slab (Naik & Joshi, 2017) (Pandey & Srivastava, 2016) (Teja et al., 2012) (J. H. Chung et al., 2011). Therefore, this review attempts to tackle the drawbacks of the bubble deck system as to perform similarly as the solid slab.

2.1 Research Questions

There are two research questions for this review. The aim of this review is to answer the following questions:

RQ1: How will the void former between the slabs affect the performance of the slab system?

RQ2: What approach can be taken to tackle the drawbacks of the bubble deck slab system?

2.2 Research Objectives

Research objectives have been determined in order to respond to the research questions for this paper:

RQ1: To study the performance of the slab system by applying different kinds of void former

RQ2: To identify the methods of solving the current limitations of the bubble deck slab system

3. Methodology

The review of the literature was done based on the procedure named Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA). PRISMA is a systematic review that will extensively screen through all the articles with relevant topics to answer a clearly defined research question, then filter the list with various inclusion and exclusion criteria to identify the reports to be included in the review (Selcuk, 2019).

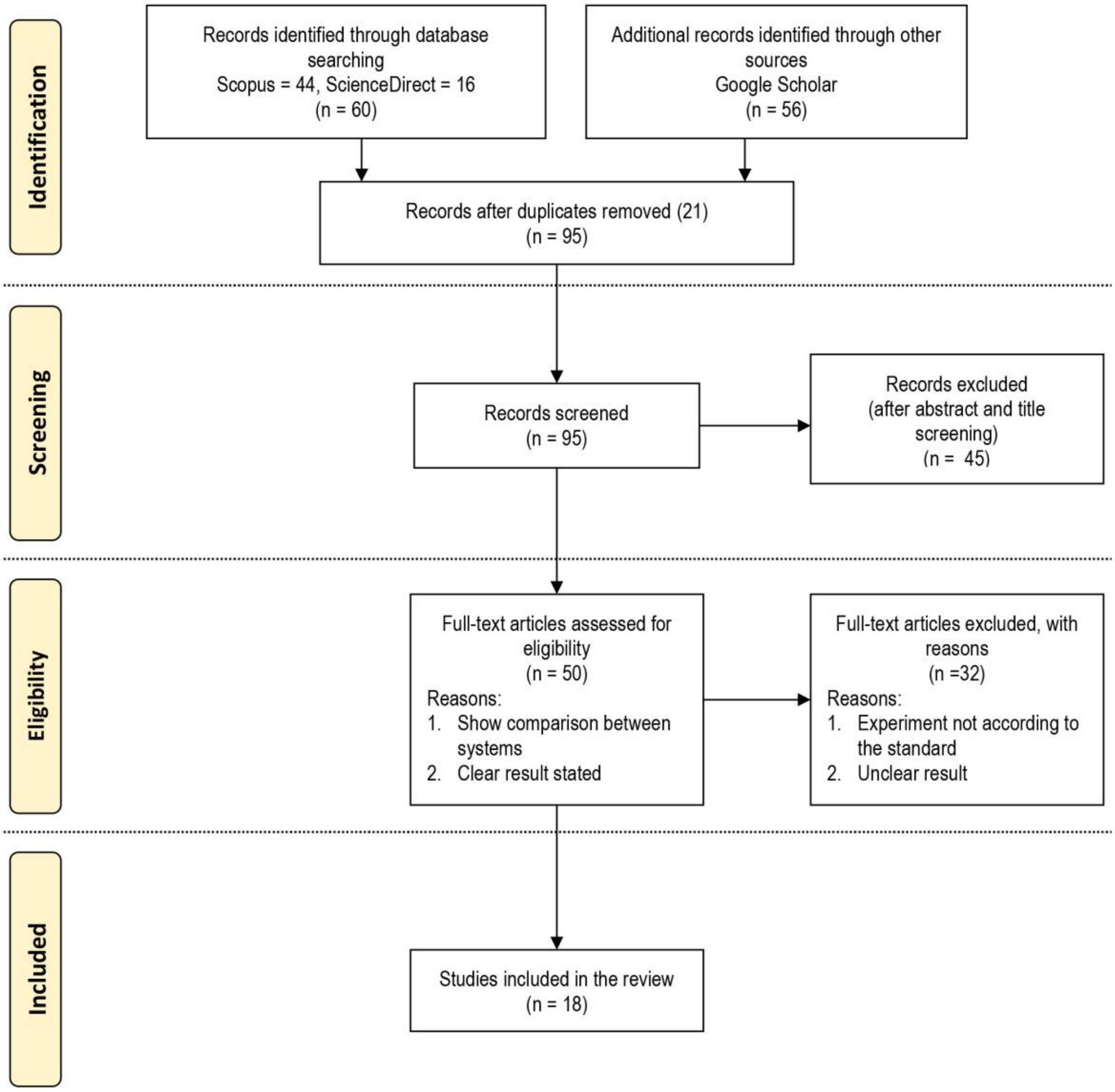


Figure 5: The frameworks for systematic and meta-analysis studies

(Source: PRISMA, 2009)

At first, the sources of electronic database were used that are Science Direct and Scopus. Additional publications were searched on Google Scholar from the reference lists of the included studies. The keyword search strategy or terms used in this review were 'bubble deck slab', 'biaxial voided slab' to mention a few. Only English published articles from the year 2010 until 2021 were being collected for this review.

All the identified articles were screened and to remove the similar or duplicated articles with same titles found in the different database. Irrelevant issues such as sound isolation performance of bubble deck slab, prestressed concrete bubble deck slabs, etc. are excluded from this review.

Next, the eligibility of the articles will be accessed through full-test screening. During the process, few articles were excluded with certain reasons such as the properties of the system is not clearly stated, insufficient data to fulfil the inclusion criteria. As a result, only 18 articles will be included in the review.

From the selected eligible articles, data such as authors, years of publication, research methodology, slab thickness, type of void formers and their final results were extracted and analysed. The extracted data were analysed using Microsoft Excel in table format and presented in graphical approach.

4. Results and Discussions

Several design criteria of the bubble deck slab system are determined such as the slab thickness, the shape and material of the void formers that could possibly affect the mechanical properties of the system to reflect the research questions and objectives.

Table 2. Summary of Systematic Review on Design and Performance of Bubble Deck Slab System extracted from Previous Studies

Author	Methodology	Slab Thickness (A) in mm	Void Former / Bubble			Ratio of B to A (B/A)	Findings
			Size (B) in mm	Shape	Material		
(Habeeb et al., 2021)	Experiment	100	80Ø	E	HDPE	0.8	The inclined shear reinforcement has the most positive effect on voided slab behaviour due to the clear reduction in shear stresses effect on the column-slab connection region
(Vinod Kumar & Hamza, 2020)	Simulation (FEA)	150	100Ø	S	HDPE	0.7	Lightweight Bubble deck slab weight reduces nearly 39% than Conventional Concrete slab models
(Amoushahi Khouzani et al., 2020)	Experiment	200	315Ø x 100 (D)	E	HDPE	0.5	The increase in the height of the plastic balls caused a decrease in shear capacity, while the increase in shear capacity by increasing the spacing between plastic balls and the supports
(Sagadevan & Rao, 2019)	Experiment	260	180Ø, 475 x 475	S, C	HDPE	0.7	The ultimate load-carrying capacity of specimens with sphere and cuboid-shaped voids was equal to that of the solid slab.
(A.M. Ibrahim et al., 2019)	Experiment	110	80Ø	S, E	PP	0.7	The result shows that bubbled slabs having spherical balls are more efficient in bearing loads than that having elliptical balls with the same amount of concrete reduction.
(Garg et al., 2019)	Experiment	120	67Ø	S	HDPE	0.6	The Bubble Deck gives much improved extramural capacity, stiffness and shear capacity of at least 70% compared to the solid slab.

(Jamal & Vijayan, 2018)	Simulation (FEA)	230	240Ø x 180 (D)	E	HDPE	0.8	Bubble deck slab with elliptical balls having GFRP sheets have better load carrying capacity and less deflection compared to that of bubble deck slab with elliptical balls
(Mohan & Sukumaran, 2018)	Simulation (FEA)	230	240Ø x 180 (D)	E	HDPE	0.8	Bubble deck slab using elliptical balls longitudinally shuffled has a better load carrying capacity and less deformation
(Joo Hong Chung et al., 2018)	Experiment	250	270 x 270 x 140 (D)	D	PP	0.5	The donut-type voided slab showed a 5% increase in load-bearing capacity and lower flexural stiffness compared to the solid slab.
(Bhowmik et al., 2017)	Experiment	230	180Ø	S	PP	0.8	The review stated that the punching shear capacity is low, which is a major problem due to the decreased weight of the Bubble Deck systems
(Jamal & Jolly, 2017)	Simulation (FEA)	230	150Ø, 240Ø x 180 (D)	S, E	HDPE	0.8	Bubble deck slab with elliptical balls has a better load carrying capacity and save weight up to 34.90% compared to 33.15% on the spherical ball
(Mushfiq et al., 2017)	Experiment	150	90Ø, 120Ø	S	PP	0.8	The finding shows that the bubble deck slabs have less load carrying capacity compared to the conventional.
(Dheepan et al., 2017)	Experiment	125	60Ø, 75Ø	S	PP	0.5, 0.6	The optimum diameter of the hollow spherical balls that can be used in bubble deck slab for normal purposes is 60mm, and the optimum spacing between the balls can be 30mm.

(Pandey & Srivastava, 2016)	Simulation (FEA)	300	65Ø	S	HDPE	0.2	Deflection and weight reduction of bubble deck are 18% more and 15% less than the solid slab respectively.
(Amer M Ibrahim et al., 2013)	Experiment	100	64Ø, 80Ø	S	PP	0.64, 0.8	A polymer bubbled slab has a saving on the concrete consumption up to 30%-45% and 30%-50%saving on energy and CO2 emissions
(Hai et al., 2013)	Experiment	230	186Ø, 240Ø x 180 (D)	S, E	PP	0.8	The voided slab with hollow elliptical balls has a better load-bearing capacity
(J. H. Chung et al., 2011)	Experiment	250	270 x 270 x 140 (D)	D	GFRP	0.5	The GFRP hollow sphere has better ultimate shear strength than the normal plastic hollow sphere
(Lai & Connor, 2010)	Simulation (FEA)	230	180Ø	S	HDPE	0.8	This investigation has proven that the Bubble Deck technology is more efficient than a traditional biaxial concrete slab in an office floor system.

S: Spherical, E: Elliptical, D: Donut-type, C: Cuboid, HDPE: High-Density Polyethylene, PP: Polypropylene, GFRP: Glass Fibre Reinforced Plastic

4.1 Concrete Slab

According to Amer M Ibrahim et al., (2013), the behaviour and performance of bubble deck slabs are influenced by the ratio of bubble diameter to slab thickness.

The result has shown that the bigger the diameter of the bubble or the void former, the lighter the weight of the bubble deck slab will be due to the elimination of excessive concrete within the slab system. However, with a bigger bubble diameter, it causes more deflection on the slab system.

4.2 Type of Void Formers

The main characteristics of the bubble deck system are that voids have been created in between the slabs using plastic balls in order to reduce the overall weight while retaining the strength and loading capacity of the slab. The plastic balls layer is commonly known as void former. Experiment and studies have been done to evaluate the performance of the slab system with different shapes, materials, configurations of void formers.

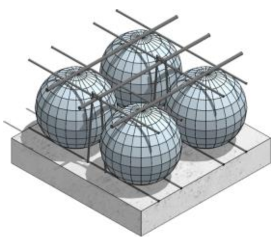
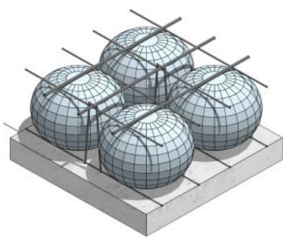
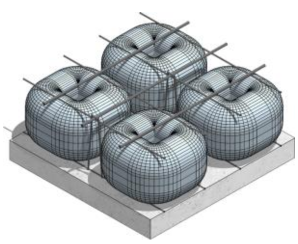
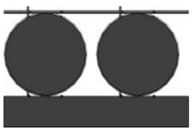
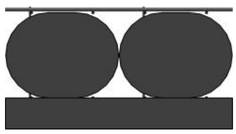
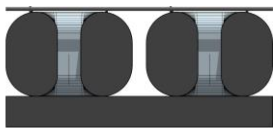
4.3 The Shape of Void Formers

The analysis of the void formers' shape is to understand and identify which type of shape could allow the bubble deck slab to perform in an optimal way. From the previous studies, the spherical shape is the most common bubble form to be used in the current slab system, at the highest percentage of 55%. 30% of the previous studies also adopted the elliptical form to carry out the experiment test to compare with the performance of the spherical form. Other than that, a small amount of studies has been using special forms such as donut-shaped.

Despite the fact that the spherical form is the common shape for the void formers, however, according to Jamal & Jolly, (2017) and Mohan & Sukumaran, (2018), the studies have shown that bubble deck slab with elliptical balls has a better load carrying capacity and lighter in weight compared to the spherical balls. Nonetheless, the statement of elliptical void formers having better load carrying capacity is contradicted with the study done by Habeeb et al., (2021), the finding shows that the bubble deck slab with spherical balls has better load-bearing capacity than those with elliptical balls with the same ratio of bubble diameter to slab thickness.

Studies from Pandey & Srivastava, (2016), Mushfiq et al., (2017) and Mohan & Sukumaran, (2018) have shown that the bubble deck slab system has greater deflection value than the conventional slab. In order to enhance the flexural stiffness of the bubble deck slab, one could design the slab with elliptical balls instead of spherical balls to lessen the deflection value. To further enhance the strength of the slab system, Jamal & Vijayan, (2018) suggested that the slab could be strengthened by using Glass Fibre Reinforced Polymer (GFRP) spread throughout the base area of bubble deck slab. This method has efficiently decreased the deflection value of the bubble deck slab by 75%.

Table 3. The shape and section of the void formers

Shape	Spherical	Elliptical	Donut
			
Section			

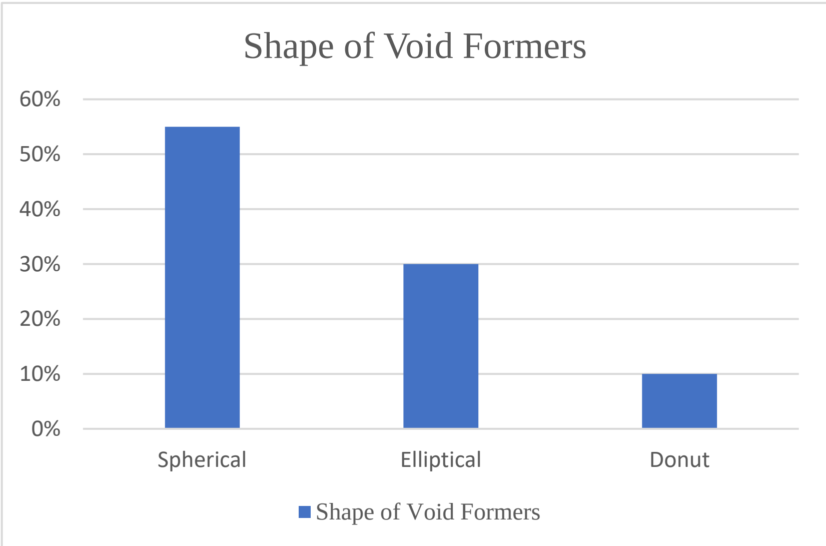


Figure 6: Shape of Void Formers of the previous studies

4.4 The Material of Void Formers

As shown the pie chart, the findings from all the previous studies show that High-Density Polyethylene (HDPE) has the highest percentage (50%) being used as the material for the void formers in the bubble deck slab, followed by polypropylene (44%) and 6% for other special materials.

The void formers or commonly known as plastic balls are the most important material for bubble deck slab system. It usually comes with the hollow sphere that is made from recycled high-density polyethylene (HDPE) or recycled polypropylene (Abg Adenan et al., 2020). Materials like polypropylene and polyethylene were found ideal because of reduced weight and act as good crack arrester (Jamal & Jolly, 2017). Both do not react chemically with concrete and reinforcement steel, has no porosity and has enough rigidity and strength to carry the maximum load. The differences between polypropylene and polyethylene are that the former one has a higher melting point, lighter in weight, not as sturdy as the later one.

In short, the plastic balls can be recycled and reused to ensure its sustainability in the construction industry.

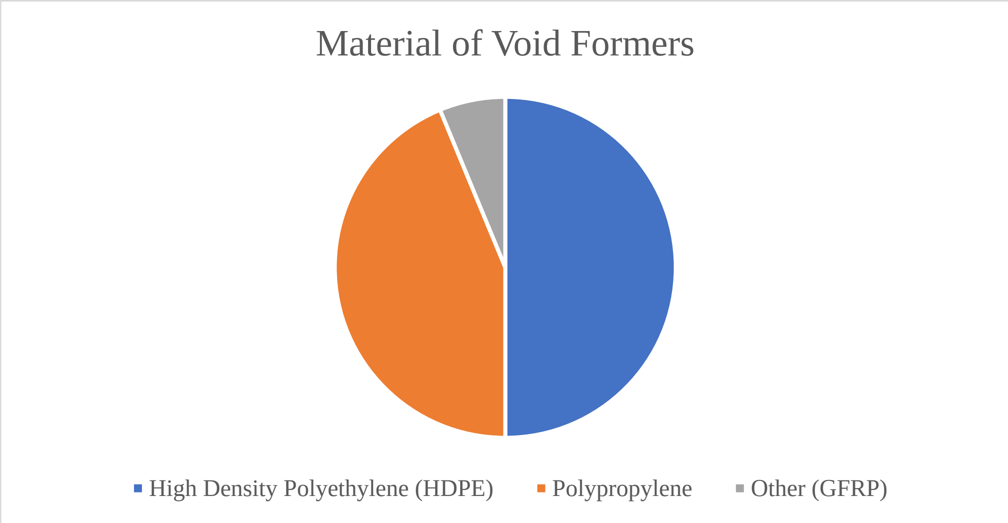


Figure 7: Material of Void Formers of the previous studies

5. Conclusion

To conclude, the bubble deck slab with HDPE hollow elliptical balls will be a better option than the one with spherical balls which minimises the drawbacks and achieve a better load-bearing capacity. To further strengthening the slab system, Glass Fibre Reinforced Polymer (GFRP) sheet can be layered within the concrete slab to lessen the deflection value. By doing so, the bubble deck system can perform with almost the same loading bearing capacity and shear strength as the conventional slab while being as an environmental-friendly technology in the construction industry. Despite the contribution of this paper, some limitations have been encountered during the study such as the choice of search terms could limit the search results; the selection of the articles included by the researcher is considered subjective.

6. Acknowledgement

The author would like to thank Universiti Sains Malaysia for giving the support and the reviewer for their comments and thoughtful ideas in assisting this paper writing.

7. References

Abg Adenan, D. S. Q., Kartini, K., & Hamidah, M. S. (2020). Comparative Study on Bubble Deck Slab and Conventional Reinforced Concrete Slab – A Review. *Journal of Advanced Research in Materials Science*, *70*(1), 18–26. https://doi.org/10.37934/arms.70.1.1826

Ahmad Halmi, N. Q., & Ismail, Z. (2017). ENVIRONMENTAL POLLUTION AND EXISTING REGULATIONS: A REVIEW ANALYSIS. *Malaysian Journal of Sustainable Environment; Vol 2 No 1 (2017): MySE.Vol.2.No.1*. https://doi.org/10.24191/myse.v2i1.5577

Amoushahi Khouzani, M., Zeynalian, M., Hashemi, M., Mostofinejad, D., & Farahbod, F. (2020). Study on shear behavior and capacity of biaxial ellipsoidal voided slabs. *Structures*, *27*(June), 1075–1085. https://doi.org/10.1016/j.istruc.2020.07.017

Berni, M., Kamaruddin, K., & Mohd, H. (2019). *Application of the Bubble Deck Slab Technology in Malaysia*. *7*(1), 43–53.

Bhowmik, R., Mukherjee, S., Das, A., & Banerjee, S. (2017). Review on Bubble Deck with Spherical Hollow Balls. *International Journal of Civil Engineering and Technology (IJCIET)*, *8*(8), 979–987.

Chung, J. H., Choi, H. K., Lee, S. C., & Choi, C. S. (2011). Shear capacity of biaxial hollow slab with donut type hollow sphere. *Procedia Engineering*, *14*, 2219–2222. https://doi.org/10.1016/j.proeng.2011.07.279

Chung, Joo Hong, Jung, H. S., Bae, B. il, Choi, C. S., & Choi, H. K. (2018). Two-Way Flexural Behavior of Donut-Type Voided Slabs. *International Journal of Concrete Structures and Materials*, *12*(1). https://doi.org/10.1186/s40069-018-0247-6

Dheepan, K. R., Saranya, S., & Aswini, S. (2017). Experimental Study on Bubble Deck Slab using Polypropylene balls. *International Research Journal of Engineering and Technology (IRJET)*, *5*(4), 716–721.

Garg, A., Goyal, A., Prince, T., Jangid, C., Hussain, A., Brahm, C., Government, P., & College, E. (2019). Bubble Deck Slab Construction and its Applications. *International Journal of Engineering Research & Technology (IJERT)*, 936–942.

Habeeb, M., Al-azzawi, A. A., & Al-zwainy, F. M. S. (2021). Journal of King Saud University – Engineering Sciences Punching shear behavior of LWA bubble deck slab with different types of shear reinforcement. *Journal of King Saud University - Engineering Sciences*, *33*(1), 15–22. https://doi.org/10.1016/j.jksues.2020.01.001

Hai, L. V., Hung, V. D., Thi, T. M., Nguyen-Thoi, T., & Phuoc, N. T. (2013). The Experimental Analysis of Bubbledeck Slab using Modified Elliptical Balls. *Proceedings of the Thirteenth East Asia-Pacific Conference on Structural Engineering and Construction (EASEC-13)*.

Ibrahim, A.M., Ismael, M. A., Abdul, H., & Abdul, S. (2019). The Effect of Balls Shapes and Spacing on Structural Behaviour of Reinforced Concrete Bubbled Slabs. *Journal of Engineering and Sustainable Development*, *23*(02), 56–65.

Ibrahim, Amer M, Oukaili, N. K. A., & Salman, W. D. (2013). *Flexural Behaviour and Sustainable Analysis of Polymer Bubbled Reinforced Concrete Slabs*. *December*, 11–13.

Jamal, J., & Jolly, J. (2017). A Study on Structural Behaviour of Bubble Deck Slab using Spherical and Elliptical Balls. *International Research Journal of Engineering and Technology (IRJET)*, *04*(05), 2090–2095.

Jamal, J., & Vijayan, V. (2018). A Study on Strengthening of Bubble Deck Slab with Elliptical Balls by using GFRP Sheets. *International Journal for Scientific Research & Development*, *6*(01), 659–663.

Lai, T., & Connor, J. J. (2010). *Structural Behavior of BubbleDeck Slabs And Their Application to Lightweight Bridge Decks*. Massachusetts Institute of Technology.

Lop, N. S., Che Ahmad, A., & Nik Zulkipli, N. A. D. (2016). THE IMPLEMENTATION OF GREEN BUILDING IN MALAYSIAN CONSTRUCTION INDUSTRY: DETERMINATION OF KEY SUCCESS FACTORS. *Malaysian Journal of Sustainable Environment; Vol 1 No 1 (2016):*

MySE.Vol.1.No.1. https://doi.org/10.24191/myse.v1i1.5561

Mohan, A., & Sukumaran, A. (2018). Performance Analysis of Bubble Deck Slab Using Elliptical Balls. *International Journal of Engineering Research & Technology (IJERT)*, *6*(06), 2–5.

Mushfiq, M. S., Student, P. G., Prof, A., Saini, S., & Nishant, A. P. (2017). Experimental Study on Bubble Deck Slab. *International Research Journal of Engineering and Technology (IRJET)*, *04*(05), 1000–1004.

Naik, S. R., & Joshi, D. (2017). A Voided Slab and Conventional Flat Slab; A Comparative Study. *IJSTE - International Journal of Science Technology & Engineering*, *4*(1), 44–50. http://www.ijste.org/articles/IJSTEV4I1016.pdf

Oukaili, N., & Merie, H. (2018). Sustainability Analysis and Shear Capacity of BubbleDeck Slabs with Openings. *2018 11th International Conference on Developments in ESystems Engineering (DeSE)*, *March 2019*, 250–255. https://doi.org/10.1109/DeSE.2018.00051

Pandey, M., & Srivastava, M. (2016). Analysis of Bubble Deck Slab Design by Finite Element Method. *International Journal of Science Technology & Engineering*, *2*(11), 599–606.

Sagadevan, R., & Rao, B. N. (2019). Effect of void former shapes on one-way flexural behaviour of biaxial hollow slabs. *International Journal of Advanced Structural Engineering*, *11*(3), 297–307. https://doi.org/10.1007/s40091-019-0231-7

Selcuk, A. A. (2019). A Guide for Systematic Reviews: PRISMA. *Turkish Archives of Otorhinolaryngology*, *57*(1), 57–58. https://doi.org/10.5152/tao.2019.4058

Serge, M., Patrick, T., & Duquenoy, F. (2016). Motion Systems: An Overview of Linear, Air Bearing, and Piezo Stages. In *Three-Dimensional Microfabrication Using Two-Photon Polymerization: Fundamentals, Technology, and Applications* (pp. 148–167). Elsevier Inc. https://doi.org/10.1016/B978-0-323-35321-2.00008-X

Teja, P. P., Kumar, P. V., Anusha, S., Mounika, C. H., & Saha, P. (2012). *Structural Behavior of Bubble Deck Slab*. *March 2015*.

Vinod Kumar, M., & Hamza, T. A. (2020). Finite element analysis on effect of different ball spacing in bubble deck lightweight concrete slab. *IOP Conference Series: Materials Science and Engineering*, *872*(1), 0–11. https://doi.org/10.1088/1757-899X/872/1/012124

Vinod Kumar, M., Siddharamaiah, Y., & Jaideep, C. (2019). Performance of fibre integrated RC frames manufactured using alternative material as aggregate for sustainable environment. *Journal of Green Engineering*, *9*(2), 201–211.

Copyright Disclaimer