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Preliminary Characteristic of Bubble Deck Slab Subjected to a Vertical Point Load

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ABSTRACT

The bubble deck slab system, formally recognised as the reinforced bubble deck slab, presents a distinctive structural solution contributing to the optimisation of building functionality and design especially in modern construction. Compared to traditional solid slabs, this study examines the initial properties of bubble deck slabs under vertical point loads, with particular attention to bending effects, deflection behaviour, and failure causes under controlled experimental conditions. The primary objectives of this study are to evaluate the deflection of both slab types, determine failure conditions, and examine the response to point loads applied at their edges with special focus on the stiffness characteristics of the slabs. This inventive slab, made of reinforced concrete, incorporates hollow plastic bubble balls made of high-density polyethylene (HDPE), which reduces the overall concrete volume compared to conventional reinforced concrete slabs. Under the shear point load applied at the centre of the slab, the bubble deck slabs exhibited superior elastic behaviour compared to their conventional counterparts. Consequently, the bubble deck slab in this study significantly reduces concrete usage. Despite the reduced concrete volume, the strength and performance characteristics of bubble deck slabs are maintained. A detailed examination of the applied loads explores their effects on flexural strength, bending stiffness, and load-deflection behaviour, providing a comprehensive understanding of the system's structural performance and potential application in sustainable building design.

Keywords: Bubble Deck Slab; Cracking pattern; Voided slab; Compressive Strength Test; Flexural Test

INTRODUCTION

Malaysian construction industry, like many others globally, is constantly seeking innovative solutions to enhance construction efficiency, reduce costs and minimise the environmental impact. These goals are met by bubble deck slabs, which are unusual in the form includes hollow plastic balls or bubble balls inside the concrete construction. The overall weight of the slab is greatly decreased while retaining structural integrity. The focus on sustainable construction methods is one of the main reasons behind Malaysia's adoption of bubble deck slabs. Bubble deck technology helps lessen the carbon footprint associated with construction activities by using less concrete without sacrificing strength. Furthermore, the lower weight bubble deck slabs lessen the structural pressure on structures, which may enable more cost-effective designs and quicker construction.

Furthermore, there is an article that presents a discussion on the environmental impact of post-tensioned voided concrete plates by analysing their embodied carbon performance. Broyles et al. (2023) have discussed this issue in detail, highlighting the advantages of using bubble deck slabs to reduce the environmental impact. It emphasises the role of these innovative slabs in promoting sustainable construction practices by reducing concrete usage, a material known for its significant environmental impact due to the high carbon dioxide emissions involved in its production. By utilising lightweight materials strategically, bubble deck slabs help mitigate environmental impact without compromising structural strength, making them an appealing option for eco-friendly construction projects.

Basically, this technology realistically removes inactive concrete from the centre of a floor slab. Technically, this area serves no structural function, allowing for more sustainable and efficient resource utilisation. Early in the twentieth century, voided slab systems were developed using segmented void formers such as spherical or oval plastic balls for two-way slab applications, aiming to reduce the weight of the concrete floor by replacing less-useful concrete in the centre with lighter material (Shah 2018). However, these hollow cavities can decrease the resistance of slab to shear and fire, posing challenges to structural integrity, prompting ongoing research to address these issues for design engineers seeking to minimise slab weight without compromising structural integrity (Cho et al. 2024).

Voided slabs, such as bubble deck slabs, are engineered to strategically remove concrete from areas of the structure where it is less critical for supporting applied loads. This removal of concrete creates voids or empty spaces within the slab, reducing its overall weight without compromising its structural integrity or load-bearing capacity. For instance, as hollow plastic spheres or bubbles of the bubble slabs are incorporated into the concrete matrix, they are displacing some of the solid material (Al-Azzawi & Mtashar, 2023). Despite this reduction in concrete volume, the slab retains its strength and performance characteristics. The innovative design ensures that the remaining concrete is strategically positioned to support the primary loads, such as those from occupants, furniture, and equipment, while the voids contribute to the overall reduction in weight (Al-Azzawi & Mtashar, 2023). This results in a slab that is as robust as a solid one but significantly lighter, offering benefits such as reduced material usage, lower construction costs, and enhanced sustainability without sacrificing structural performance.

In earlier construction methods, reducing the overall slab weight was often pursued to allow for a decrease in slab thickness, which consequently led to a reduction in load transferred to columns and foundations. This approach was made possible due to the use of lighter structural components. However, in cases where longer spans were required. Voided slabs were introduced as a solution, offering greater design flexibility especially in structures with irregular column placements (Dheepan et al. 2021). Additionally, plastic-void slabs prove to be lighter compared to traditional slab construction methods.

The adoption of bubble deck slabs in the Malaysian construction industry reflects a broader global trend towards sustainable and innovative building practices. By strategically removing inactive concrete from the centre of floor slabs, bubble deck technology significantly reduces concrete without compromising structural integrity. This approach not only lessens the carbon footprint associated with construction activities but also offers cost-effective designs and quicker construction processes. Despite historical challenges, ongoing research continues to address concerns related to shear resistance and fire protection of the bubble deck. Overall, bubble deck slabs represent a promising solution for environmentally conscious construction projects, offering reduced material usage, lower costs, and enhanced sustainability while maintaining structural performance.

To build upon these findings and address the identified gaps, this research aims to systematically investigate the performance characteristics of bubble deck slabs under various loading conditions and material compositions. This study will focus on evaluating the bending behaviour, failure modes, and cracking patterns of conventional solid slabs and bubble deck slabs under edge point loads, offering a comprehensive comparison of their structural performance.

METHODOLOGY

A systematic comparison of the structural behaviour of conventional slabs and bubble deck slabs is required to evaluate the performance of bubble deck slabs under vertical point loads. Two types of slabs conventional and bubble deck were constructed with identical dimensions of 1500 mm x 1500 mm x 235 mm at the Laboratory of the Faculty of Civil Engineering Technology, University Malaysia Pahang Al-Sultan Abdullah. Hollow high-density polyethylene (HDPE) spheres are incorporated into the bubble deck slab's structure to reduce dead weight while maintaining load-bearing capacity.

The testing procedure began with the preparation of both slab types, ensuring that the same grade and quality of materials were used for casting. To ensure the consistency and dependability of results, controlled circumstances were used for the casting and testing of both conventional and bubble deck slabs. The preparation of high strength for the casting procedure will involve concrete with a 25 N/mm^2 design strength. HDPE spheres were placed in a specified grid to form voids in the bubble deck slabs, lowering the volume of concrete without compromising structural integrity.

Steel bars were used as reinforcement, organised in a consistent grid pattern to maximise strength and allow for the spherical spaces in the bubble deck slabs without sacrificing the layout of the reinforcement. The same grade and quality of materials were used to cast both slab types to provide a fair comparison.

A hydraulic loading platform that could impart vertical point loads incrementally to replicate real-world load conditions was used for the testing. Load cells, strain gauges, and linear variable differential transformers (LVDTs) were among the instruments positioned at crucial locations including the borders of slab and centre. Throughout the testing procedure, these instruments offered accurate readings of deflection, strain, and load-bearing capability.

Key comparative criteria, such as ultimate load capacity, deflection under loading, fracture propagation patterns, and failure modes, were used to assess performance of the slab. In comparison to conventional slabs, these measures provide a comprehensive understanding of the bubble deck slab for punching shear resistance and structural efficiency. All casting and testing operations were conducted in a controlled setting with constant humidity and temperature to remove outside effects and guarantee the accuracy of the findings.

EXPERIMENT MATERIAL PROPERTIES AND CASTING

The main flexural reinforcement of the conventional and the bubble decks was made of steel wire mesh DA6 with high-yield strength of 500N/mm^2. All reinforcement bars were arranged with a spacing of 100 mm centre-to-centre, as illustrated in Figure 1 for the conventional slab and Figure 3 for the bubble deck slab. A concrete cover of 30 mm was provided for both slabs. The grade 25 N/mm^2 used in this study was intended to reach its target compressive strength after 28 days of curing. Water-dispersed acrylic copolymers were applied on the surface during the curing process to improve hydration and reduce moisture loss.

The detailing of the reinforcement layout for the conventional slab is shown in Figure 1, which presents the plan view. In addition, Figure 2 presents the sectional view of the slab specimen along section A-A. For the bubble deck slab, the reinforcement detailing is illustrated in Figure 3 for the plan view and in Figure 4 for the sectional view along section A-A. In preparing the bubble deck slab sample, high-density polyethylene (HDPE) with a 180mm diameter was added into one of the slabs. It consisted of natural sand as fine aggregate, crushed stone of the nominal maximum size of 20mm as coarse aggregate, fresh ordinary Portland cement and tap water, respectively. The conventional and bubble deck slabs were cast at the Concrete Laboratory of the Department of Civil Engineering Technology as shown in Figure 5.

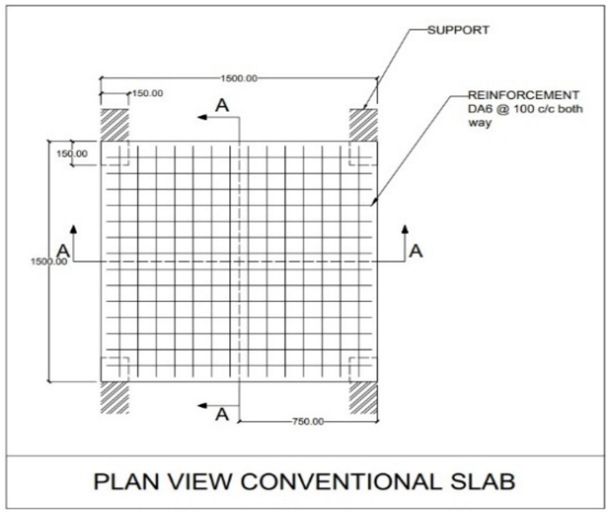

FIGURE 1. Plan view of conventional slab

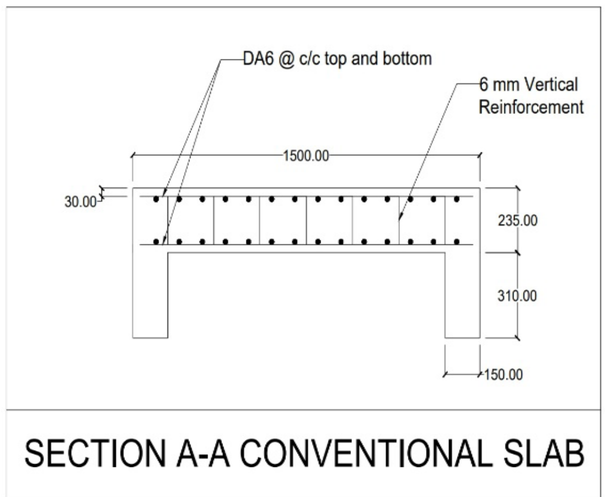

FIGURE 2. Section A-A of conventional slab

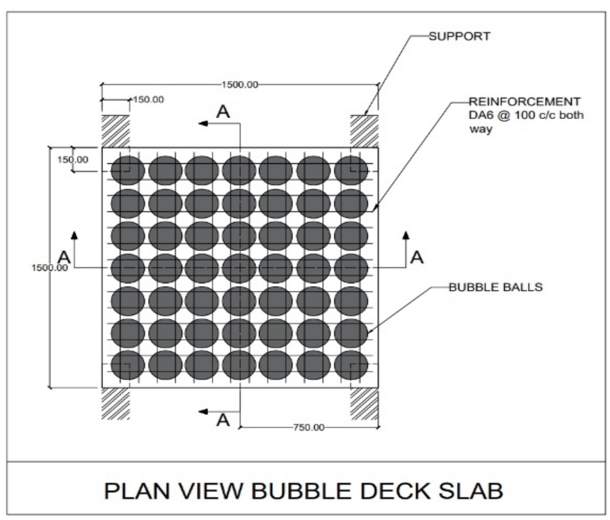

FIGURE 3. Plan view of bubble deck slab

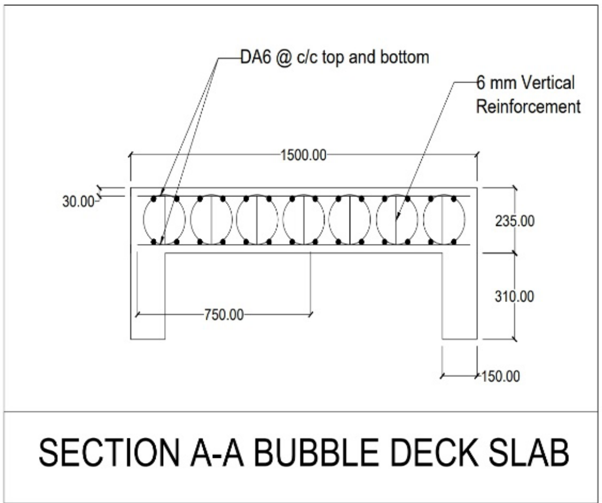

FIGURE 4. Section A-A of bubble deck slab

FIGURE 5. Concrete casting

EXPERIMENT EQUIPMENT, TESTING AND LOADING PLAN

Vertical point loads were then applied centrally on both slabs to simulate real-world conditions, with the loading incrementally increased until failure occurred. During this process, deflections at various points on the slabs were measured using a data logger and readings were recorded to establish a load-deflection curve for both slab types using Linear Variable Differential Transformers (LVDTs). The load gradually increased, and the maximum load sustained before significant failure or excessive deflection was recorded as the maximum capacity.

Failure analysis was carried out by recording each slab's mode of failure with an emphasis on ultimate load capabilities, deflection behaviour, and cracking patterns. Due to its smaller concrete volume, the bubble deck slab was expected to have a lower overall load-bearing capacity. However, because of its creative design, it was anticipated to function well under certain loads. The deflections in the bubble deck slab were expected to be greater than those in the conventional slab because of its hollow structure, which would be critical in assessing its suitability for various applications.

Additionally, differences in cracking patterns between the two types would provide insights into their structural integrity under similar loading conditions. This comprehensive methodology not only facilitates a direct comparison between the conventional slab and the bubble deck slab but also contributes valuable data toward understanding how voided slabs can be effectively utilised in modern engineering applications, ultimately informing future designs aimed at optimising material use while ensuring structural safety and performance

The deflection was measured using three Electrical Linear Variable Distance Transducers (LVDT) with accuracy of 0.01mm, positioned as LVDT 1 to LVDT 3 on the slab surface, as shown in Figure 6. In this study, the compressive strain on the top surface of the concrete slab was monitored using three High-Performance Materials (HPM) electrical strain gauges (SG). Each gauge had a length of 10 mm and a resistance of 120 Ohms, designated as SG 1 to SG 3, as illustrated in Figure 7. These gauges were positioned to observe strain development in the compression zone, particularly near the applied point load. The slabs underwent testing under load using hydraulic jacks with a 500 kN capacity. They were positioned horizontally between the jack and a sturdy steel frame, all tested under the condition of being simply supported slabs. Each slab had a loaded plate dimension of 150mm x 150mm x 25mm.

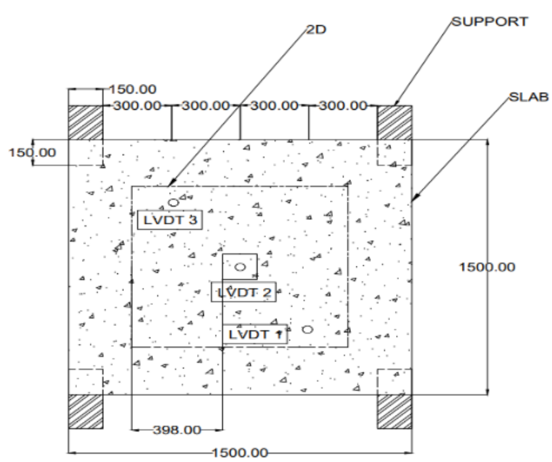

FIGURE 6. The arrangement of LVDT devices for the slab specimen

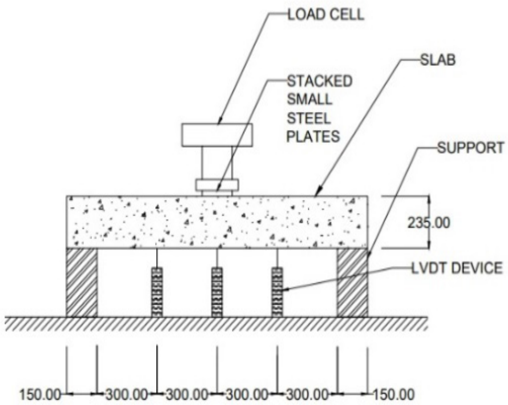

FIGURE 7. Schematic drawing of the punching shear Loading Test

A schematic sketch of the punching shear loading test and the placement of the LVDT devices for the slab specimen are shown in Figure 3, which shows the experimental setup developed to comprehend the punching shear behaviour of conventional slabs and bubble deck slabs.

To simulate real-world boundary circumstances, both kinds of slabs were simply supported on all four sides, permitting free rotation along the supports. To recreate the punching shear condition, a central load was given to the slabs and progressively raised until failure occurred. Throughout the test, the applied load and associated deflections were recorded to ascertain the slabs' stiffness and load-bearing capacity.

Flexural rigidity also was measured, represented by the equation EI, which is a crucial parameter in understanding the bending behaviour of structural slabs, including conventional and bubble deck slabs. The unit of EI is in kNm^2. In this context, E denotes the Young's modulus, which quantifies the material's stiffness, while I represent the moment of inertia of the slab of the cross-section, reflecting its geometric properties. The EI equation in bending stiffness is defined in Equation (1), where w is the maximum area load carried by the specimen during testing with the unit being kN/m^2, s/w is the self-weight of the slab with the unit being kN/m^2, L is the span length with the unit being m, and f_{max} is the maximum deflection with the unit being m.

$$EI = \frac{5(w+s/w)L^4}{384 f_{max}} \quad (1)$$

The elastic range, as represented in the evaluation of the ductility index (DI), is a critical parameter in assessing the deformation capacity of structural slabs, particularly in distinguishing between brittle and ductile failure modes. Ductility Index is defined as the ratio of ultimate deflection to yield deflection and is a dimensionless value. In this context, the elastic range corresponds to the portion of the load-deflection curve. The yield point marks the end of this range, after which plastic (irreversible) deformation occurs. The ductility index (DI) is determined using equation (2), where is the ultimate deflection (in mm), and is the yield deflection (in mm). A higher DI indicates greater ductility, signifying better energy absorption and deformation capability before failure.

$$DI = \frac{\delta u}{\delta y} \quad (2)$$

In traditional slabs, cracks usually form at the load application point and propagate outward. However, in bubble deck slabs, cracks frequently started around the voids and followed a more intricate pattern. Careful inspections were undertaken to monitor the initiation and progression of cracks.

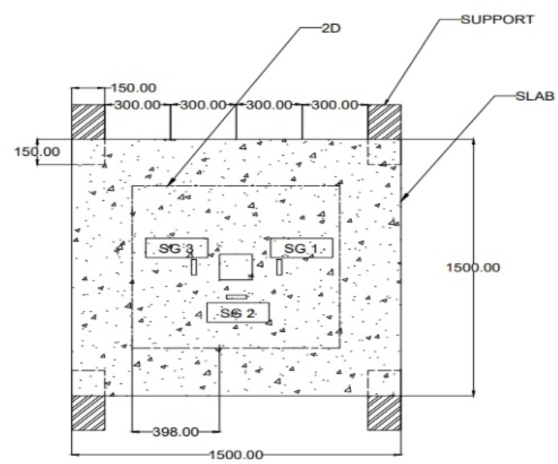

FIGURE 8. The arrangement of strain gauge

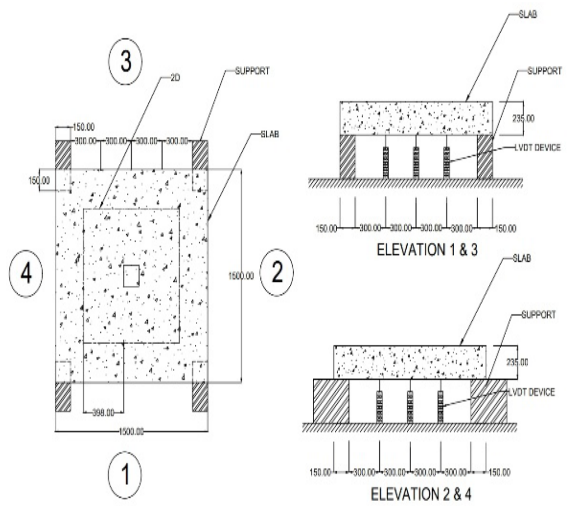

FIGURE 9. Elevation view for both slab specimen

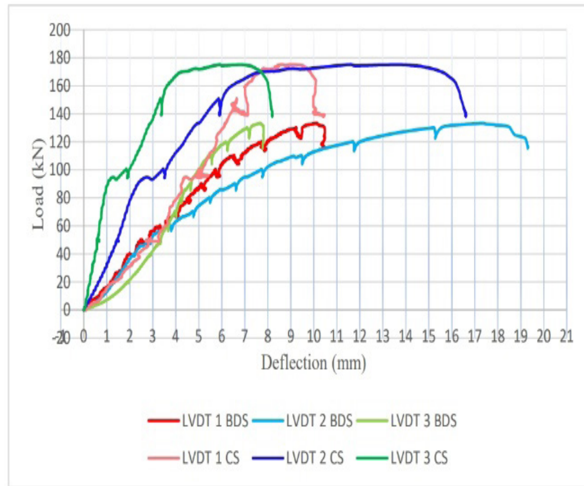

FIGURE 10. Comparison load vs deflection of conventional slab and bubble deck slab

The detailed experimental setup is illustrated in Figure 8 and Figure 9. Figure 8 and Figure 9 show the arrangement of strange gauge and the elevation view for both slab specimens respectively. It was meticulously designed to evaluate the punching shear behaviour of conventional and bubble deck slabs. By strategically placing instrumentation, ensuring consistent support, and loading conditions, the experiment provided valuable data on strain distribution, crack development, and overall structural performance, contributing to a deeper understanding of the advantages and challenges associated with bubble deck slab technology.

RESULTS

DEFLECTION

Figure 10 shows a comparison of the load versus deflection responses between the conventional slab and the bubble deck slab. The load was applied centrally to the top surface of the slab specimens for both conventional and bubble deck slabs. This loading method is crucial for inducing flexural stresses and observing the corresponding deflections, thereby assessing the flexural strength of the slab.

The conventional slab exhibited a higher maximum load capacity by achieving 170 kN compared to 130kN in the bubble deck slab, indicating a 23% variation. This indicates that the conventional slab can bear a higher load before reaching its failure point. The deflection of the conventional slab increased steadily with the applied load. Initially, the slab showed a linear deflection profile, which became non-linear as the load approached the maximum capacity, indicating the onset of plastic deformation and eventual failure.

A structural element of flexural rigidity has a major influence on its capacity to resist bending under applied loads. For a conventional slab, the flexural rigidity is measured at 1394 kNm², this value represents a substantially higher with different 67% compared to the bubble deck slab which measured only with a flexural rigidity of 449.65 kNm² in term of flexural rigidity. The difference in stiffness between the two slabs is illustrated in Figure 10 evidence that the conventional slab is stiffer than the bubble deck slab. This considerable difference highlights the inherent stiffness advantage of the conventional slab, due to its continuous and solid material composition. The conventional slab can resist deformation and bending better because of its higher moment of inertia.

However, because the bubble deck slab has hollow spheres in its structure, which reduces the effective cross-sectional area and moment of inertia, it has less flexural rigidity. This reduces the rigidity of the bubble deck slab while also significantly reducing its weight, which benefits certain applications in terms of load control and material efficiency. The flexural rigidity of the bubble deck slab is 32% of that of the conventional slab. This trade-off emphasises the need to select slab types based on the balance between structural performance requirements and design objectives.

The data provided in Table 1, includes the maximum load and maximum deflection measured by the conventional slabs and the bubble deck slabs. This measurement of conventional slabs and the bubble slabs offer important insights into their structural performance under punching load conditions. The conventional slab has a greater maximum load capacity of 170 kN, in contrast to the bubble deck slab, which has a capacity of 130 kN. This indicates that the conventional slab can withstand a higher load before failure. However, this comes at the cost of increased material usage and weight.

The deflection for conventional slab measurements indicates a more uniform distribution of stiffness across different positions. The central position shows moderate deflection, while the edge and intermediate positions exhibit less variation. Meanwhile, the deflection behaviour for the bubble deck slab is more variable across different positions. The central position shows a slightly higher deflection, but the edge position of the bubble deck shows significantly higher deflection with the intermediate position shows lower deflection compared to the conventional slab. This variability suggests that while the bubble deck slab maintains overall structural integrity, it experiences different levels of stiffness and flexibility in different areas.

Besides that, the bubble deck slab's higher deflection at the edges suggests potential issues with serviceability in certain areas, although its performance in the intermediate position is better. This indicates a need for careful consideration of load distribution and reinforcement placement in bubble deck slab designs. Despite the lower maximum load capacity, the bubble deck slab uses less concrete, making it more efficient in terms of material usage. The variable deflection behaviour, while a potential concern, is mitigated by the overall reduction in weight and material costs.

The cracking patterns of the conventional slab and the bubble deck slab are shown in Figure 11 and Figure 12, respectively. These figures illustrate the crack propagation and failure characteristics observed during the testing process. The conventional slab exhibited more visible and concentrated cracking near the centre, indicating typical flexural failure. In contrast, the bubble deck slab displayed a more scattered cracking pattern, particularly around the void areas, suggesting different stress distribution and failure mechanisms due to the presence of voids.

In summary the data from Table 1 illustrates that while the conventional slab has a higher load-bearing capacity, the bubble deck slab offers greater material efficiency with some trade-offs in deflection behaviour. The bubble deck slab exhibits significantly higher central deflection but shows smaller deflection at the edge location, suggesting areas where design improvements could enhance performance. Overall, bubble deck slabs provide a promising alternative to conventional slabs, particularly when optimised for load distribution and reinforcement placement to address the observed deflection characteristics.

TABLE 1. Maximum load and deflection for conventional slab and bubble deck slab

Position of LVDT	Conventional Slab		Bubble Deck Slab	
	Load (kN)	Deflection (mm)	Load (kN)	Deflection (mm)
LVDT 1	170	10	130	10.6
LVDT 2	170	8.1	130	19.2
LVDT 3	170	16.5	130	7.8

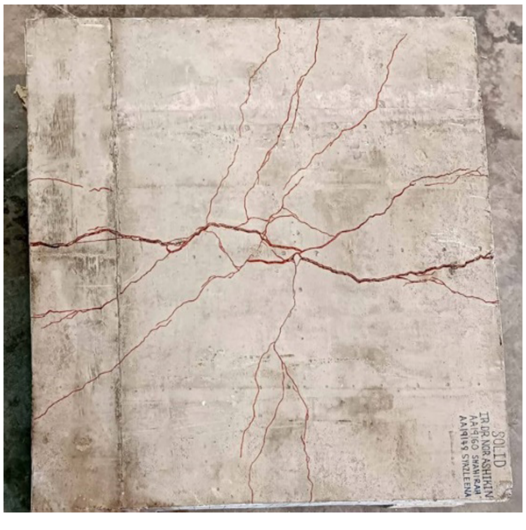

FIGURE 11. Cracking pattern of conventional slab

FIGURE 12. Cracking pattern of the bubble deck slab

LOAD-STRAIN RELATIONSHIP

The load vs. strain relationship for bubble deck slabs and conventional slabs subjected to punching shear loading provides key insights into their structural behaviour under applied loads. The data illustrated in Figure 13 and Figure 14 show the response of different sections of the slabs in terms of strain under increasing load for conventional and bubble deck slabs, respectively.

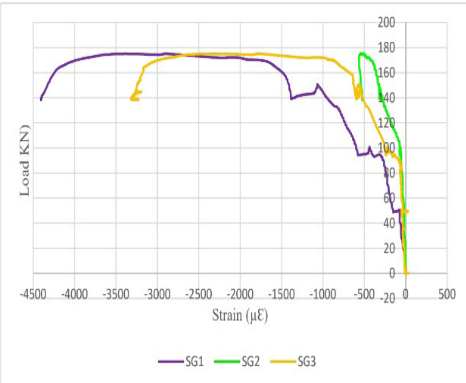

FIGURE 13. Load vs strain of conventional slab

Firstly, the conventional slab exhibits considerably higher compressive strains, with SG 1 measuring 4400 µƐ, compared to the bubble deck slab, where SG 1 measures 1270 µƐ, representing a 71% difference. This indicates that the bubble deck slab incorporating voids helps reduce compression stress concentrations, potentially leading to improved serviceability of the structure and performance under similar loading conditions. The higher compressive strains in the bubble deck slab, with SG 2 measuring 1290 µƐ compared to 700 µƐ in the conventional slab, which the difference is 45%. This indicates that bubble deck slabs are effective in reducing compressive stress.

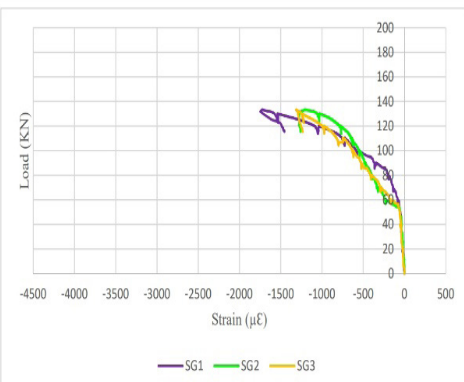

FIGURE 14. Load versus strain of bubble deck slab

Secondly, the higher strain values in compression of the conventional slab indicate a more concentrated stress distribution, which can lead to higher peak stresses and potentially earlier failure if not properly reinforced. In contrast, the lower strain values in the bubble deck slab suggest a more distributed stress profile, reducing peak stresses and potentially increasing the slab's ability to handle loads more effectively.

Thirdly, the higher strains in the conventional slab imply it may require more material or reinforcement to handle the same loads without exceeding strain limits, whereas the lower compressive strains and more efficient stress distribution in bubble deck slabs suggest they achieve similar or better performance with less material, enhancing material efficiency and sustainability.

Lastly, the load versus strain data demonstrates that bubble deck slabs exhibit superior performance in terms of reduced compressive strains and more efficient stress distribution compared to conventional slabs. The conventional slab, while having higher load-bearing capacity, shows significantly higher strain values, indicating concentrated stress points that could lead to earlier failure. In contrast, the bubble deck slab, with its innovative design incorporating voids, shows lower strain values, reflecting better stress management. This highlights the bubble deck slab's potential for improved durability, material efficiency, and overall structural performance in modern construction. However, the increased compressive strains in bubble deck slabs underscore the need for careful design and reinforcement to ensure comprehensive structural integrity.

ELASTIC BEHAVIOUR

Furthermore, the experimental data also reveal that bubble deck slabs experience reduced deflection under the same loading conditions compared to conventional slabs. The presence of voids effectively decreases the slab's weight, thereby lessening the overall load-induced deflection. This reduction in deflection implies that bubble deck slabs can better maintain their shape and structural integrity under load, enhancing their serviceability, especially in applications where minimal deflection is crucial.

Moreover, the incorporation of voids in bubble deck slabs leads to an improved stress distribution across the slab. The voids act as stress relievers, preventing localised stress concentrations that could otherwise lead to crack initiation and propagation. This even distribution of stress helps to prevent the formation of significant cracks within the elastic range, maintaining the slab's structural integrity and durability.

The results from the experimental setup demonstrate that bubble deck slabs exhibit superior ductile behaviour compared to conventional slabs, as shown in Figure 10 and calculated using Equation (2). The average ductility index (DI) for the bubble deck slab is 7.14mm, which is significantly higher than the 3.52mm calculated in the conventional slab. This indicates that bubble deck slabs can undergo greater deformation beyond the elastic limit before failure, signifying a more ductile response. Such behaviour is characterised by enhanced energy absorption capacity, improved structural resilience, and better post-yield performance. These properties contribute to greater serviceability, durability, and material efficiency, making bubble deck slabs a robust and advantageous option in modern construction. Their ability to perform effectively under various load conditions while using less material makes them a preferred choice for sustainable and resilient building designs.

DISCUSSION

The performance of the two slab types of changes significantly as shown by the load against deflection curves. In comparison to the bubble deck slab, which could support a maximum load of 130 kN, the conventional slab demonstrated a maximum load capacity of 170 kN. This increased load capacity implies that traditional slabs can support heavier loads before failing, which is useful in applications where high strength is required.

However, as the conventional slab reached near to its maximum capacity, its linear deflection profile changed to a non-linear response, signifying the beginning of plastic deformation. The load-deflection curve of the bubble deck slab, on the other hand, showed a steeper slope, suggesting stronger flexural rigidity despite its lower load capacity. Based on this stiffness, the bubble deck design successfully reduces deflection under applied loads, which is essential for preserving structural applications' serviceability.

The analysis of the load-strain relationship reveals that conventional slabs experience higher compressive strains up to 4400 $\mu\varepsilon$ compared to the bubble deck slabs up to 1270 $\mu\varepsilon$. This indicates that the design of bubble deck slabs, which incorporates voids, effectively reduces stress concentrations and may enhance durability by distributing loads more evenly across the slab. On the other hand, the higher compressive strains observed in bubble deck slabs up to 1290 $\mu\varepsilon$ compared to conventional slabs up to 700 $\mu\varepsilon$ suggest potential concerns regarding compressive failures. This necessitates careful design considerations for compressive reinforcement placement to ensure comprehensive structural integrity.

The lower strain values in the bubble deck slabs imply a more efficient stress distribution profile, which can potentially increase their ability to handle loads without exceeding strain limits. This efficiency highlights the advantages of using less material while achieving comparable or superior performance under similar loading conditions.

According to the results, bubble deck slabs are more rigid than regular slabs because their load-deflection curves have a steeper initial slope. By adding voids, the slab's overall weight is decreased and its resistance to deformation under applied stresses is improved. Bubble deck slabs' longer elastic range enhances their serviceability and durability by enabling them to withstand greater loads before experiencing plastic deformation.

Furthermore, localised stress concentrations that can cause crack initiation and propagation are avoided because of the voids' enhanced stress distribution. This characteristic is very helpful for preserving lifespan and structural integrity under various load scenarios.

CONCLUSION

The comparative analysis of conventional slabs and bubble deck slabs in the Malaysian construction industry underscores significant advancements in structural engineering and sustainable construction practices. This study highlights the superior attributes of bubble deck slabs, which are innovatively designed with hollow plastic spheres embedded within the concrete matrix to reduce concrete without compromising structural integrity.

Bubble deck slabs achieve substantial weight reduction by strategically eliminating inactive concrete, thereby decreasing material usage and promoting sustainable construction practices by reducing the carbon footprint linked with concrete production. The adoption of bubble deck technology in Malaysia aligns with global efforts to enhance sustainability in construction. By minimising concrete usage, bubble deck slabs contribute to lower CO_2 emissions, addressing one of the key environmental concerns in the industry (Dinesh et al. 2020).

Experimental findings indicate that conventional slabs surpass bubble deck slabs in maximum load capacity, yet the latter display greater material efficiency, sustaining around 90% to 96% of the ultimate load compared to solid slabs. Despite lower load capacity, bubble deck slabs exhibit superior flexural rigidity, showing less deflection for a given load, indicative of higher stiffness which this finding agreed with Green et al (2018). While conventional slabs present predictable crack patterns primarily characterised by flexural cracks, bubble deck slabs display more complex cracking patterns due to voids, requiring careful design and reinforcement. Moreover, bubble deck slabs demonstrate superior strain distribution with reduced compressive strains and more efficient stress management, potentially enhancing durability.

The incorporation of plastic voids not only reduces the self-weight of the slab but also improves the stress distribution and deformation capacity, allowing the slab to sustain higher loads before yielding. These outcomes reinforce the assertion that bubble deck systems are structurally efficient and capable of enhanced elastic and post-elastic performance under applied loading.

The findings suggest that bubble deck slabs are a promising alternative to conventional slabs, especially for environmentally conscious construction projects. Their reduced concrete and material usage offer cost-effective design solutions and quicker construction processes. However, the variability in deflection behaviour and the need for careful reinforcement design to manage compressive stress and complex cracking patterns highlight areas for further research and optimisation which was suggested by Mahdi et al (2021).

Overall, the adoption of bubble deck slabs represents a significant step towards achieving sustainable and efficient construction practices in Malaysia. By leveraging innovative design and material strategies, bubble deck technology not only addresses environmental concerns but also enhances structural performance and material efficiency. Ongoing research and development will be crucial in refining these systems to maximise their potential in the construction industry.

RECOMMENDATION

Recommendations for further research include exploring the use of bubble deck slabs, despite their lower flexural strength, with special handling and design, particularly in car park constructions. Additional investigations should involve multiple slabs for each type to determine average slab performance, consideration of shear links in slab design to assess shear cracking, examination of rectangular slabs to reduce size, and a study of finite elements to understand cracking under shear loading with and without shear reinforcement. A comparison between laboratory experiments and numerical studies can provide valuable insights.

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DECLARATION OF COMPETING INTEREST

None.

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