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Structural Performance of Reinforced Concrete Double Layer Bamboo Bubble Slab Under Uniformly Distributed Load

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ABSTRACT

The architectural use areas in the structure are formed by reinforced concrete (RC) slabs, which transport vertical loads to the beams, columns, load-bearing walls, and shear walls. The slab is an important structural member of reinforced concrete building structures and concrete-intensive parts of structural members. . The slab deflects significantly when the load acting on the slab or the clear span between columns is large. As a result, the slab's thickness increases to accommodate the load received. Since this slab's self-weight increases as the thickness increases, the slabs get heavier and causes the slab unable to withstand the load and to produce cracks on the surface. At the turn of the twentieth and twenty-first centuries, the creation of the bubble deck slab became an innovation to replace conventional slab. This study used bamboo as the bubble material in reinforced concrete bubble slab. This study examined and assessed the mechanical properties and structural behaviour of bamboo as a bubble in supported reinforced concrete double-layer bamboo bubble slab under a uniformly distributed load. In this research, 500 mm x 1250 mm x 175 mm supported reinforced concrete slabs C25 (1 sample) and C30 (1 sample) with double layer (DL) bamboo bubble slabs were constructed. Both samples were compared with the control sample (CS) for each slab type. It was found that the maximum displacement occurred at the centre of the slab, with 6.45 mm for DL25 and 6.89 mm for DL30. According to stress-strain analysis, the double layer bamboo slab produced a lower stress value than the control sample. Since the values were smaller than 2, DL25 and DL30 slab performed better for the ductility factor than CS25 and CS30. As a result, the displacement, ductility and section capacity were improved by employing bamboo as a bubble material in a reinforced concrete slab.

Keywords: *reinforced concrete bubble slab, bamboo bubble slab, structural behaviour, ductility factor, energy absorption*

1. INTRODUCTION

Steel and concrete are used in traditional reinforced concrete structures. This structure is constructed due to its ability to bear high loads, ease of building, and longevity, among other factors. During this time, there has been a great growth in time. Particularly in the previous two decades, housing and infrastructure have been in high demand and most of them are made with reinforced concrete structures. Reinforced concrete slabs are critical structural components in

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buildings because they transport and transfer loads to beams and effects due to impact loading on buildings, which may severely damage the structure and lead to disproportionate partial collapse; therefore, it is worth investigating the response of a structure or its components under concentrated loading [1,2]. The fundamental design limitation used in creating slab systems in a reinforced concrete construction has caused peripheral beams or very thick slabs, making it necessary to build a larger slab between the columns. As a result of large volumes of used concrete, the structure's weight is increasing due to low section capacity. The best way to resolve such building issues is using bubble deck technology. This technology creates air voids while giving strength through arch action using spheres composed of recycled industrial plastic. It attempts to take advantage of the benefits of concrete slab construction while limiting the disadvantages of solid slabs by reducing the structure's self-weight [3].

When the load acting on the slab or the clear span between the columns is large, the slab deflects significantly. As a result, the slab's thickness increases to accommodate the load received. Since this slab's self-weight increases as the thickness increases, the slabs get heavier and cause the slab to be unable to withstand the load, producing cracks on the surface. Other than that, reinforced concrete slab was found to produce a high amount of concrete; therefore, it also promotes Carbon Dioxide (CO_2) emission. This is agreed by the previous study, which stated that 278 tones of CO_2 emission may be produced from 1000 m^2 of site concrete [4]. This emission includes transporting concrete trucks to the site and factory concrete production [5]. In addition, due to concrete carbonation and chloride penetration, the passive coating may be destroyed, resulting in the commencement of corrosion processes. Reinforcement corrosion damages include not only steel reinforcement strength and ductility loss but also concrete cover cracking due to volumetric corrosion product expansion and bond degradation of the steel-concrete interface due to the loss of cover confinement [6].

Bamboo cancan be utilized as an alternative to traditional building materials in various components of a building, such as a roof structure, walls, foundation and scaffolding [7]. Bamboo also has characteristic features high in strength, like air void, durability and so on, that are the same as plastic bubble deck [8]. Not only that, many studies have been conducted to diversify the innovation of bubble slabs and further diversify the use of bamboo in construction, considering that bamboo has the same characteristics as plastic balls, is easily available in Malaysia and has high tensile strength [7,9]. Using bamboo as an alternative material in the bubble slab was found to reduce the use of concrete and increase the tensile strength of the bubble slab. This study used bamboo as the bubble material in reinforced concrete bubble slab. Bamboo bubble slab as a new technology is very effective in reducing the load of the slab self-weight. The innovation of bamboo bubble slab can reduce the volume of the concrete and cross-sectional area [10] because the slab was designed with bamboo as additional components [3]. Reducing the slab self-weight without reducing the strength is possible, as studies have effectively promoted sustainability in reinforced concrete structures. Higher slab self-weight can form cracks on its surface [11].

Bubble slab is a new technology used as a hollow concept using bubble plastic balls and other bubble materials to create voids between structures. By replacing the middle of the slab with plastic balls, the concrete volume decreases, and will reduce slab's self-weight significantly [12]. Tube deck, a one-way composite voided slab system, is identical to the bubble slab concept, which employs a plastic ball as the bubble material [13]. Normally, circular paper tubes are used to create voids for one-way composite voided slab system, and profiled steel

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decks with T-shaped ribs serve as the form as shown in Figure 1. After the in-situ concrete cures, they generate composite activity as well. This method integrates cast-in-place voided slabs with a profiled steel deck to improve structural efficiency and enhanceconstructability and environmental performance. As a result, where construction factors exclude the use of a precast hollow core slab, the suggested approach may be a viable alternative [14].

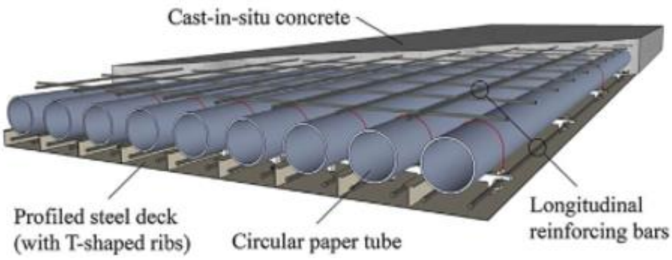

Figure 1: Tube-Deck Slab System Illustration [13]

In the overall review, an alternative sustainable material should be found as bubble material could replace the current practices of bubble slab without reducing its structural performance. This study examined and assessed the failure mechanism and structural behaviour of bamboo as a bubble in supported reinforced concrete double-layer bamboo bubble slab under a uniformly distributed load.

2. METHODOLOGY

The methodology was carried out to analyse the structural performance of supported reinforced concrete double-layer bamboo bubble slab under uniformly distributed load, as shown in Figure 2. The methodology involved material testing, sample preparation, experimental set-up and testing. All materials were tested using a UTM machine and reaction frame at Structural Laboratory, UiTM Pulau Pinang, to examinetheir mechanical properties and structural behaviour. The data obtained in this research were used to analyse the mechanical properties and structural behaviour of supported reinforced concrete double-layer bamboo bubble slab under uniformly distributed load.

2.1 Material testing

In material testing, each material used in this study was required to be tested to determine the material properties in terms of tensile and compressive strength for bamboo and the tensile strength of BRCA8. In this study, concrete Grade C25 and C30 were designed and used for the reinforced concrete slab. Meanwhile, fresh and hardened concrete was tested to examine the workability and compressive strength. In the fresh concrete stage, a slump test was done to produce better workability, as shown in Figure 3(a). After the concrete cube starts to harden, the curing process takes place for a maximum of 28 days. Compression test is shown in Figure 3(b). In order to ensure the tensile strength reinforcing fabric of steel (BRC) meets the requirements, a tensile test is conducted, as shown in Figure 3(c). Three specimens of BRC A8 were tested to get the steel reinforcement average tensile strength and elasticity.

Bamboo is defined as an alternative material for bubble application used in this study. Before starting the sample preparation, an average of 50 mm diameter and 5 mm thickness of bamboo

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must be dried to ensure no moisture in the bamboo stem, as referred to in Figure 3(d) the natural environment. Moisture in bamboo can y influence the structural performance of the reinforced concrete slab, which may exhibit cracks from temperature, shrinkage and load effect [14]. Compression and tensile testing takes place to obtain bamboo compressive strength [15]. Next, the bamboo performed a tensile test on three different parts of the bamboo, which are the top, middle and bottom, as shown in Figure 3(e) [16]. These three parts produced different tensile values depending on the hardness factor of the bamboo on the particular part and also the thickness of the dog-bone specimen size. This test was performed until the failed, and the reading value began to decline. For the compression test involving three different areas of the bamboo's top, middle, and bottom, a compression test was conducted as shown in Figure 3(f). Depending on the thickness of the specimen size and the specific part's hardness factor, these three parts provided different comprehensive results. This test was carried out until the specimen failed and the reading value started to fall.

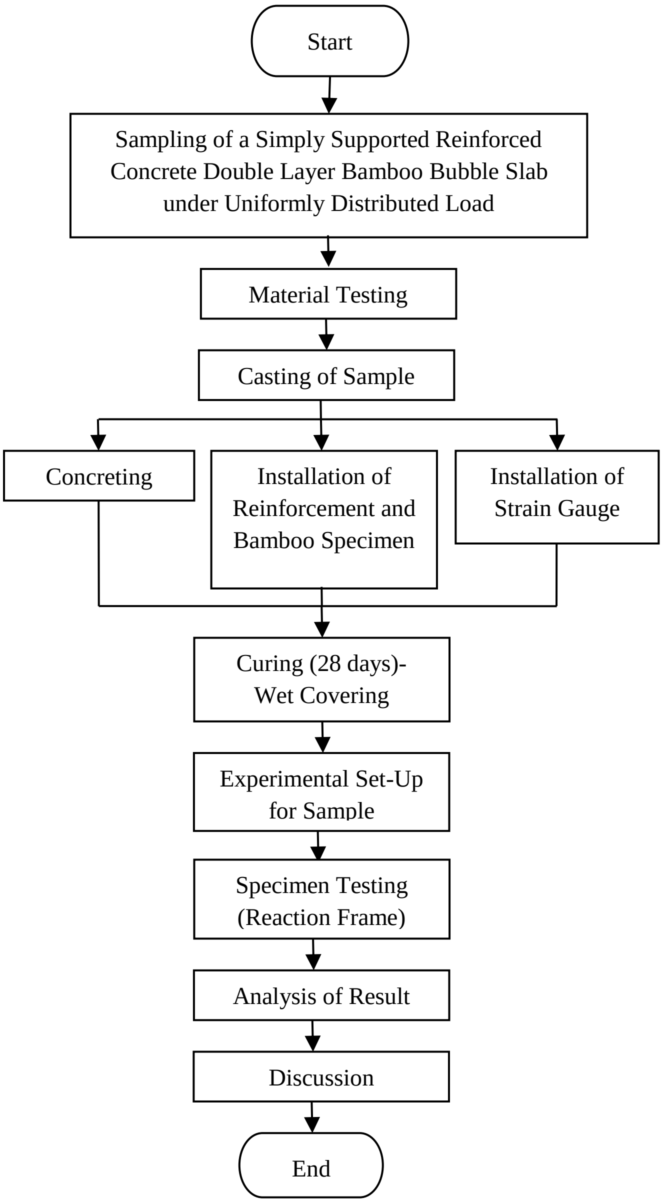

Figure 2: Research Methodology Flowchart

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(a) (b) (c) (d) (e) (f)

Figure 3: Testing of Material (a) Slump Test; (b) Compression Test of Cube Concrete; (c) Tensile test of BRC A8; (d) Drying Process of the Bamboo; (e) Dog-bone of Tensile; (f) Bamboo of Compression.

2.2 Sample Preparation

Four samples were prepared in this study, which included reinforced concrete double-layer bamboo bubble slab Grade C25 (DL25), Grade C30 (DL30) and control samples Grade C25 (CS25) and Grade C30 (CS30). Figure 4 shows the overall process of reinforced concrete double-layer bubble slab sample preparation. Figure 4(a) shows the formwork of a reinforced concrete double-layer bamboo bubble slab and control sample dimensions, which are designed for 1250 mm (length) x 500 mm (width) x 175 mm (thickness). The double layers of bamboo were sandwiched in between BRC, as shown in Figure 4(b), to produce the void effect of the reinforced concrete slab. In order to examine and analyse the structural performance of the reinforced concrete bubble slab, four steel strain gauge size 5 mm was installed into the reinforced concrete bubble slab sample underneath the bottom BRC A8 at the left, middle and right side as shown in Figure 4(c) to determine the strain behaviour at the support and middle span of the slab. Another concrete strain gauge size of 30 mm was installed at the middle top of the slab as it is defined as the critical location of the slab. All strain gauges should be checked before testing to ensure it is functioning to record the resistance varies, resulting in a changing electrical output so that it can measure pressure, force, weight or tension of the bubble slab. The sandwich double-layer bamboo bubble slab was placed into the formwork with a 50 mm concrete covering at the bottom. Then, concrete was poured into the formwork, and the surface was levelled, as shown in Figure 4(d). Figure 4(e) shows the slab taking place in the curing process for 28 days using the wet covering method.

(a) (b) (c) (d) (e)

Figure 4: Casting of the slab (a) Formwork of Slab; (b) Arrangement Sandwich Between Mesh Wire and Bamboo; (c) Installation of Strain Gauge for BRC A8; (d) Slab concrete is completely levelled; (e) Wet Covering for Curing Process.

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2.3 Experimental Set-up and Testing

The testing examined the structural performance of reinforced concrete double-layer bamboo slabusing a reaction frame 0f 1000 kN. The slab sample was placed on a support platform with a width of 500 mm on the frame section. Before lifting the slab, strain gauges for the reinforced concrete slab wereere installed on the surface, as shown in Figure 5(a) to ensure that it is not loaded under the steel plate attached to the load actuator. While lifting the sample to be placed on the reaction frame, it must be done carefully to avoid damage to the sample. After the sample was placed on the support reaction frame, a Linear Variable Differential Transformer (LVDT) was installed at the centre of the span under the slab, as shown in Figures 5(b) and 5(c), respectively. The LVDT needle should touch the sample to record the displacement reading during the experimental work. Before starting the testing, all strain gauge wires and LVDT need to be connected to the data logger and the initial reading is checked before the testing. Strain gauge and LVDT produce the reading of slab strain and displacement. The load actuator was connected to the computer to record the sample's load behaviour. This study tested two specimens of reinforced concrete slab control sample and two reinforced concrete double layer bamboo bubble slabs to examine and assess their structural performance.

(a) (b) (c)

Figure 5: Testing of Slab (a) Strain Gauge on Slab Surface; (b) Slab on Support of Reaction Frame; (c) Installation of LVDT Under the Slab Specimen.

3. RESULTS AND DISCUSSION

Results and discussion provide details in understanding the research findings to answer the research objectives. The reason is being provided to confirm the accuracy of findings concerning the study's initial objectives. This study used data collected from an experimental study to examine the failure mechanism and structural performance of a reinforced concrete double-layer bamboo bubble slab. The outcomes were compared between the control sample slabs and the double layer bamboo bubble slabs. The fracture pattern on the slab surface was observed to answer the failure mechanism. Meanwhile, the load displacement, ductility factor, stress-strain behaviour, and energy absorption of the slab were discussed in the structural behaviour of the structure. Overall, the results and discussion of this study are divided into five sections: crack pattern, load-displacement behaviour, ductility factor, stress-strain behaviour and energy absorption.

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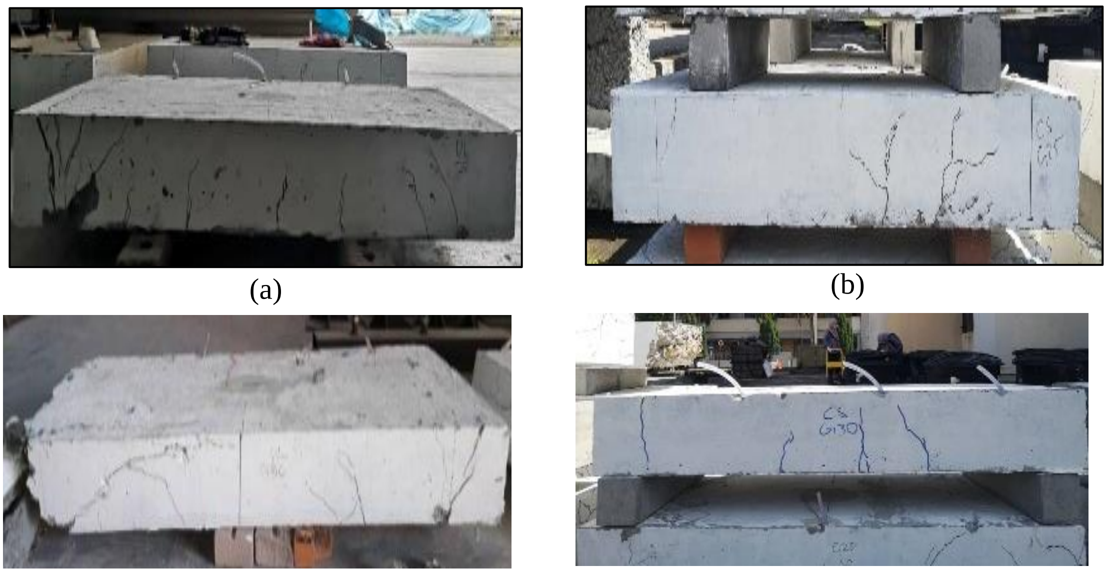
3.1 Crack Pattern

The crack patterns found in this study for reinforced concrete double-layer bamboo bubble slab are shown in Figure 6. In this study, the finding was analysed to identify the failure mechanism of reinforced concrete double-layer bamboo bubble slab (DL25 and DL30) and control sample slab (CS25 and CS30) in terms of crack pattern to find out the effect of bamboo as a bubble material whether there are changes for the crack pattern of reinforced concrete slab under uniformly distributed load. The testing on supported reinforced concrete of the control sample and double layer bamboo bubble slab produced several types of crack patterns with different locations and the initial appearance of cracking at different load values.

Based on the results, the analysis found shear and tension because the slab supported the slab. Based on the observation, the support area had a higher tendency of cracks than other sections for CS25 and CS30. Cracks easily crept all over the section for the control sample (CS25 and CS30) due to the low ductility of the section being reinforced by BRCA8 compared to reinforced concrete bamboo bubble slabs (DL25 and DL30). This is also agreed upon when the applied load contacts the slab's upper surface under the serviceability limit state [17]. As a result, the support continued to be under strain, leading to more cracks because it is considered the maximum stress location at the middle span. The tendency for the slab to deform is significant, which results in a shear crack close to the support region and a tension crack at mid-span. This is also agreed by De Maio et al. (2022) [17], where the shear and tension crack propagation focuses on these areas.

In addition, reinforced concrete for the control samples showed more crack propagation thandouble-layer bamboo bubble slabs, as shown in Figure 6(b) and Figure 6(d). This is influenced by the amount of concrete used by these two types of slabs where additional reinforced element do not support it. The large volume of concrete helps to increase the strength of the structure to receive the load applied when compression ,but additional reinforced elements canare carry the tension behaviour of the structural elements.



(a) (b) (c) (d)

Figure 6: Crack Patterns (a) DL25; (b) CS25; (c) DL30; (d)CS30.

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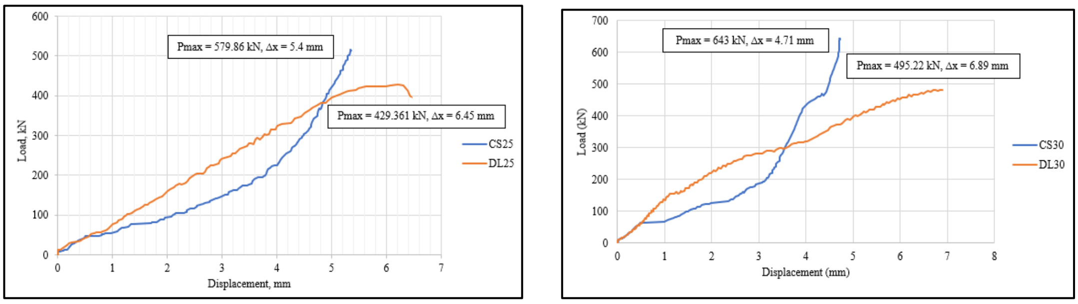
3.2 Load Displacement Behaviour

Load displacement behaviour was analysed for the reinforced concrete control sample and double layer bamboo bubble slab of Grades C25 and C30. This analysis was performed to identify the maximum load and displacement of the reinforced concrete slab. The load and displacement were recorded until the samples failed under serviceability. Figure 7 shows the overall load-displacement behaviour of reinforced concrete control and bamboo bubble slab.

After the load-displacement analysis in this study, it shows that concrete Grade C30 (643 kN) can withstand higher loads than Grade C25 (579.86 kN) due to the stronger properties of concrete itself with a difference of 10%. The maximum load value of the double layer bamboo bubble slab for both concrete grades was lower than both grades of the control sample because the volume of concrete of the double layer bamboo bubble slab was lower than the control sample. It is also agreed by Shetkar and Hanche (2015) [18] that the reduction of concrete volume may affect the stiffness of the slab. However, loads imposed on double-layer bamboo bubble slab are acceptable and safe to use for pedestrian bridges or low-rise buildings. After all, the design strength for the concrete meets the structural performance requirement of more than 20 MPa.

The displacement shown by the double layer bamboo bubble slab is higher than the control sample at an average of 23%. This is because bamboo has high tensile strength and good compressive strength, giving an increasing effect of strength at the section. When exposed to tensile pressure, concrete has a very low tensile strength, roughly one-tenth of its compressive strength, so it splits. As a result, reinforcements are frequently used in tension zones to transmit tensile pressures and minimize fracture widths [19]. Bamboo can withstand the load imposed on the double layer bamboo slab for a longer period due to the advantages of elasticity on its properties compared to the control sample. In addition, with the increase of the strength grade, the brittleness level of concrete gradually increases, and the ductility decreases [20]. Overall, it was found that the load is proportional to the displacement of the structural element.



(a) (b)

Figure 7: Load-Displacement Behaviour (a) Grade C25; (b) Grade C30.

3.3 Ductility Factor

The volume of concrete used also affects the ductility index of the structure. This is because concrete is a material that has a high compression rate. The durability of concrete in receiving high loads makes its ductility high. In addition, using bamboo in reinforced concrete slab is acceptable because the ductility index value for double layer bamboo bubble slab is still in the

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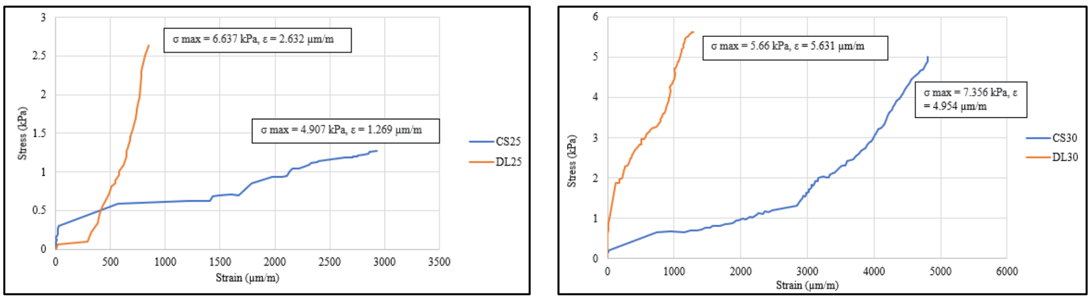
range below nine by referring to Eurocode 8 based on load and displacement behaviour. If the ductility index is above nine, the design for reinforced concrete becomes complex. In addition, concrete grade also affects the value of the ductility index because the higher the concrete grade value, the higher the isconcrete grade, and the higher the isconcrete grade value, the higher its strength. Table 1 shows the ductility factor of concrete grades C25 and C30. The ductility index produced for reinforced concrete double-layer slab was found to be good and effective because the value is 2.00 for DL25 and 1.20 for DL30. This is agreed by Gilbert et al. (2008) [21], where the structural ductility of a slab between 1 to 2 is considered a safe value for normal strength concrete where it can absorb and dissipate energy without significant loss of load resistance.

Table 1: Ductility Factor of Concrete Grade C25 and C30.

Sample	Δu	Δy	Ductility Index
Control Sample C25	0.102	0.042	2.43
Double Layer C25	0.114	0.057	2.00
Control Sample C30	0.291	0.081	3.59
Double Layer C30	1.281	1.071	1.20

3.4 Stress-Strain Behavior

The result of stress-strain behaviour for concrete slab samples DL25 and CS25 is shown in Figure 8(a), while the result for samples DL30 and CS30 is shown in Figure 8(b). The use of bamboo in reinforced concrete slabs has a positive impact on stress-strain behaviour for sample DL25. The stress experienced by DL25 was greater than CS25 because bamboo properties produce high elasticity and can carry more stresses. When the load is applied, bamboo can sustain the load for a long period, so the strain value for DL25 is bigger than strain CS25. Besides the bamboo being able to improve the stress-strain behaviour of reinforced concrete slabs, the concrete grade also affects the result of stress-strain behaviour. In addition, the largest value of concrete grade also helps to increase the performance of stress behaviour for concrete grade C30. The grade of concrete increases the stress value of CS30, while the value of strain shows that DL30 is better than CS30 because the properties of bamboo itself can sustain the load for a long time.



(a) (b)

Figure 8: Stress-Strain Behaviour (a) C25; (b) C30.

Overall, it is agreed that the stress-strain proportional increases with a significant difference between the control sample and bamboo bubble slab samples where DL25 and DL30 carry more stresses with low strain values. The results are relevant to represent the structural behaviour. Although bamboo's location is near the neutral axis, it is located more at the tension zone at

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about 10% from the compression zone. Therefore, the previous study agreed with this study, where bamboo is identified as a suitable alternative material for concrete reinforcement because it creates strength and flexural behaviour of the structure [22].

3.5 Energy Absorption

Energy absorption is defined by referring to the area under theload-displacement curve. The average load acting on the control sample and double layer bamboo bubble slab for C25 and C30 is recognized. To obtain the percentage of energy absorption, the values of load and deflection should be taken at the initial and ultimate points in the load-displacement graph. As shown in Table 2, the energy absorption percentage of the control sample grade C25 is lower the thanfor double layer bamboo slab with the values 0.01 per cent and 0.03 per cent, respectively. The energy absorption percentage for grade C30 showed the same result pattern as grade C25 since the value of the double layer bamboo bubble slab was 4.58 percent, which was higher than the control sample of 0.04. The factor that influences energy absorption capacity is pore size. Bamboo is one of the materials that can be used to absorb energy. The fibrous texture of bamboo with air space in the middle is very suitable as an energy absorption material [7]. This result shows that bamboo application in reinforced concrete slab also gives positive energy absorption results. The double layer bamboo bubble slab's energy absorption is better than the control sample's. The elasticity of bamboo also affects the result because it can sustain the load applied over a long period.

Table 2: Energy Absorption of Control Sample and Double Layer Bamboo Bubble Slab.

Location	Parameter	CS25	DL25	CS30	DL30
Initial	Load (P), kN	8.41	13.8	13.27	145.96
	Deflection (δ), mm	0.045	0.057	0.081	1.071
	Energy(E_{int}), kN.mm	0.37845	0.7866	1.07487	156.3232
Ultimate	Load(P), kN	579.86	429.36	643	495.22
	Deflection (δ), mm	5.4	6.21	4.71	6.89
	Energy(E_{int}), kN.mm	3131.244	2666.326	3028.53	3412.066
% Initial Energy Absorption		0.01	0.03	0.04	4.58

4. CONCLUSION

This study was conducted based on the objectives of the failure mechanism andassessing the structural behaviour of supported reinforced concrete double-layer bamboo bubble slab under uniformly distributed load. Based on the objectives, the main outcomes of this study are drawn as below:

- The volume of concrete used influences the result of the failure mechanism and structural performance of reinforced concrete slab.
- Installing double layer bamboo inside the reinforced concrete slab increases the displacement of the slab, while the load experienced by the control sample slab is greater than the double layer bamboo bubble slab. However, the load experienced by the double-layer bamboo bubble slab is acceptable.
- The volume of concrete used influences the ductility index of the reinforced concrete slab. However, the ductility index for double-layer bamboo bubble slab is acceptable.

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- Reinforced concrete of double layer bamboo bubble slab produces better stress-strain behaviour than control sample slab due to bamboo's elasticity, which can sustain the load applied longer than the control sample slab.
- Energy absorption for a layer bamboo bubble slab results better than the control sample slab—The bamboo's characteristic with air space in the middle influences the energy absorption performance.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest involving other organization or entity (with a financial or non-financial) that has no financial bearing in the materials discussed in this manuscript.

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