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Flexural Behaviour of the Two-Way Spanning Reinforced Concrete Slab Using Spherical Plastic Bubble Balls

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Flexural Behaviour of the Two-Way Spanning Reinforced Concrete Slab Using Spherical Plastic Bubble Balls

N A Muhamad Khairussaleh, R Omar, S Mat Aris, M F Mohd Nor, M A Mohd Saidi and N M A Nik Mohd Mahari

Faculty of Civil Engineering Technology, Universiti Malaysia Pahang, Gambang, 26300, Pahang, Malaysia.

Abstract. The use of conventional reinforced concrete in the construction industry increases each year, especially in developing countries. However, the concrete content, particularly cement production contributed to the greenhouse gas emission subsequently increase to climate change. Thus, the reinforced concrete slab containing high-density polyethene (HDPE) hollow spherical plastic bubble balls also known as bubble deck slabs were introduced for sustainable construction. This type of slab forms a slab that has less concrete volume compared to the normal solid reinforced concrete slab. Although this unique system can facilitate up to a 50% longer span compared to the conventional reinforced concrete solid slab, yet, it can cause the performance of the slab structure such as flexural and shear capacity may be affected due to the thirty to forty per cent of fewer concrete volumes. Hence, this paper studies the comparison of the performance of the two-way supported slabs; reinforced bubble deck slab and normal solid reinforced concrete slab after being subjected to the area loading. The square slabs are 1200mm by 1200mm in width and length with a thickness of 235mm. The investigations of the experiments included flexural strength, bending stiffness and load-deflection behaviour due to the impact of the area loading. Also, the crack propagation and crack pattern which differs also was shown for each type of slab system, especially in shear strength.

1. Introduction

In the twentieth century, the symbol of modern life is the Concrete Age as the use of concrete in the construction industry seems never to stop after World War II. However, the production of concrete that has increased each year comes to a massive environmental cost which contributes to the environmental problem [1]. According to [2], cement manufacturing is an energy-intensive industry that consumes 12 – 15% of total energy use. This cause a huge emission of CO_2 to the environment. This is equivalent to the 2.5 billion tonnes of carbon dioxide (CO_2) per year that come from cement production alone which is about 8% of the global total [3]. With the environmental impact of concrete is estimated to get worse by the year 2050 [4], construction professional players are urged to get the balance right in reducing the production of CO_2. Due to this climate emergency, it is time to adopt target in reducing uncontrolled embodied carbon by focusing on the efficiency of structure design [5]. Thus, the use of the bubble deck system in building construction as sustainable concrete could be one of the efficient ways to set the carbon target generated during construction. This is because the bubble deck slab system used for the building construction may reduce the concrete used by up to 35% depending on the scale of the project [6,7].

Generally, the bubble deck is a floor system by removing the inactive concrete at the central of a floor slab by replacing it with plastic spheres. A significant amount of concrete volume that has been 'evacuated' remove the selfweight of the slab approximately results by 35% [8]. Moreover, according to [4,9], the use of this system in construction shall reduce the normal slab weight by 30 - 50%. The use of this system gives better flexibility and larger space to the building as the building can facilitate up to 50% longers spans with very minimum columns. The bubble deck firstly was proposed used in Denmark in 1990s and widely use later in Europe countries, yet, this technology was used in Malaysia in 2011. Although it has been introduced in Malaysia for more than 10 years, the implementation of this system is with a limited project [1]. Lai [10] mentioned that the hollow cavities of the bubble deck systems not only substantially reduce the slab's resistance to shear and fire but also affect its structural integrity. In recent years, there are studies of bubble deck slabs [11-15]. Yet, the need for further investigation especially the load spreading and the crack propagation which measured its main structural integrity has to be more scrutinised [1]. Therefore, the performance of the bubble deck slab needs to be thoroughly investigated to assure the robustness and high strength of its structure. Thus, the objectives of this study are:

a) Investigating the bending behaviour of a two-way spanning of a reinforced conventional solid slab and reinforced bubble deck slab subjected to area loading.
b) To study the failure behaviour and propagation of cracks of reinforced bubble deck slabs and reinforced conventional solid slabs that have been subjected to area loads.

2. Methodology

There was three segments in the methodology that will be explained differently in this section.

2.1. Materials

For this study, a ready-mixed concrete C25/30 concrete grade was provided by Pamix Sdn Bhd. Meanwhile, the reinforcement steel bar meshes DA6 BRC with a high yield of 500 N/mm^2 was sponsored by EC EXCEL Wire Sdn Bhd. The details of the material characteristic used for both slabs used in this study are shown in Table 1.

Table 1. Material characteristics of the reinforced slabs, conventional slab (SS) and bubble deck slab (BD).

Characteristic	Type of Slabs	
	Conventional Slab (SS)	Bubble Deck Slab (BD)
Concrete grade, f_{ck}	C25/30	
Yield strength of reinforcement, f_{yk} (N/mm^2)	500	
Type of reinforcement bar mesh	DA6 BRC	
Type of spherical bubble ball	N/A	HDPE
Diameter of the spherical bubble ball (mm)	N/A	180

To ensure less impact on the quality of the concrete, the delivery of concrete should be allowed for 90 minutes until discharge. Figure 1 presents the ready-mixed delivered by concrete mixture truck from Gambang plant while Figure 2 shows the type of DA6 BRC reinforcement that was used for this study.

Figure 1. Ready-mixed delivered concrete.

Figure 2. DA6 BRC reinforcement.

The volume of the slabs will be occupied with bubble balls, hence, a total of 72 HDPE spherical hollow plastic bubble balls with 180mm diameter will be used. Figure 3 shows the HDPE hollow plastic bubble balls in constructing the bubble deck slab specimens.

Figure 3. HDPE plastic sphere bubble balls.

2.2. Two –ways Slab Specimens Preparations

The two ways spanning of reinforced bubble deck and conventional concrete slab specimens were constructed in the concrete laboratory of Universiti Malaysia Pahang (UMP). Both slabs were square slab specimens size 1200mm x 1200mm with 235mm thickness. The 25mm concrete cover was designed for both types of slabs and constructed with reinforcing rebar DA6 (6mm in diameter with 100mm spacing). Figure 4 and Figure 5 are the arrangement detail of the bubble deck slab specimens that are used in this study.

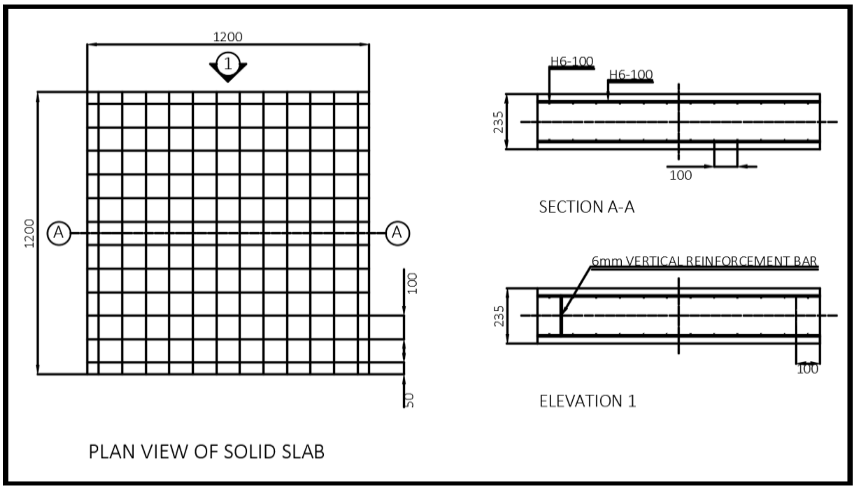


Figure 4. Top view of the solid slab (SS)

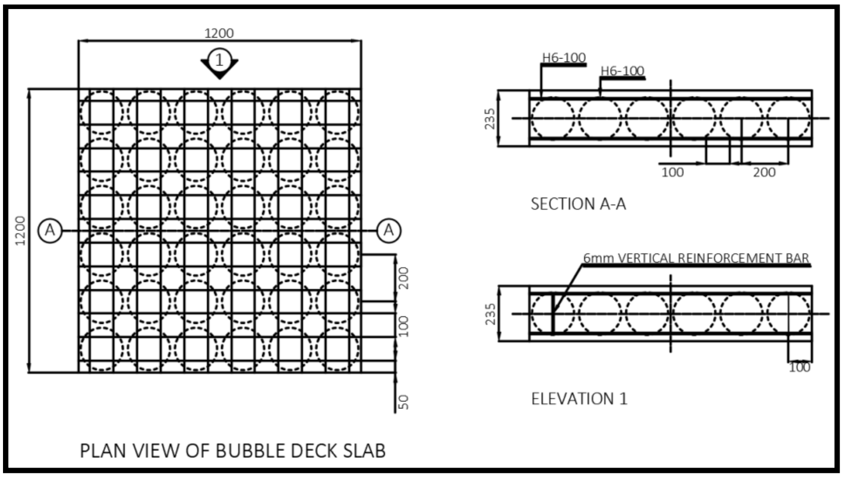


Figure 5. Top view of the bubble deck slab (BD)

Compared to the reinforced conventional solid slab specimen, more technical work in the laboratory was required to prepare the reinforced bubble deck slab (BD). This is due to the bubble balls will be floating to the concrete surface during the concreting process. Thus, the timber clamping was placed on top of the formwork to reduce this problem as shown in Figure 6 (a). Also, the top and bottom reinforcements were suitably tied together with iron wire at the corner and center of the reinforcement lattice as shown in Figure 6 (b) in order to ensure the bubble balls are kept in the arranged line/row.

(a) Placing timber plank on top of the formwork

b) Iron wire tied between the top and bottom reinforcement lattice.

Figure 6. Bubble deck slab (BD) specimen before concreting.

2.3. Experimental Set-up

Linear Variable Differential Transformer transducer or LVDTs was used in the slab flexural testing and the set-up of this device is presented in Figure 7 and Figure 8.

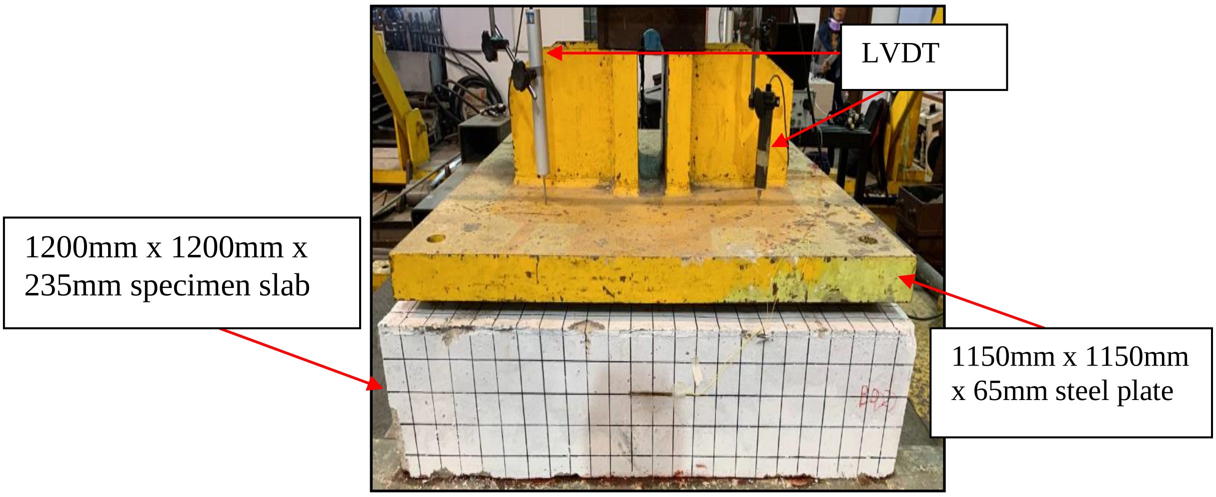


Figure 7. LVDT devises set-up for the slab specimens

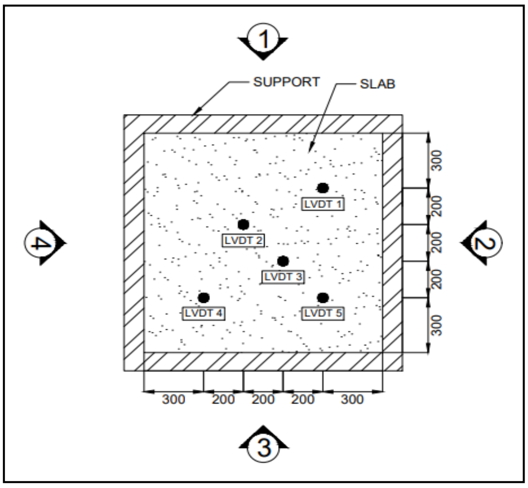


Figure 8. The planning of LVDT device arrangements on the slab specimens

The LVDT arrangements on the top of the slab specimen as shown in Figure 7 were due to the difficulty of the LVDT set up underneath the slab specimens. This is because the investigation of slabs was in two-way spanning and there was no space to place the LVDT devices below the slab specimens. In addition, the loading applied on the slab need to be spread acting as a uniformly distributed area loading. Therefore, thirty steel plates sized 200 x 200 x 25 mm were placed on the surface of the slab. Then, a big steel plate sized 1500 x 1500 x 75 mm was placed on top of the steel plate 200 x 200 x 25 mm as shown in Figure 9. The schematic diagram of the area loading test for the two-way spanning slab is presented in Figure 10.

Figure 9. Uniformly distributed area loading with different steel types of steel plates.

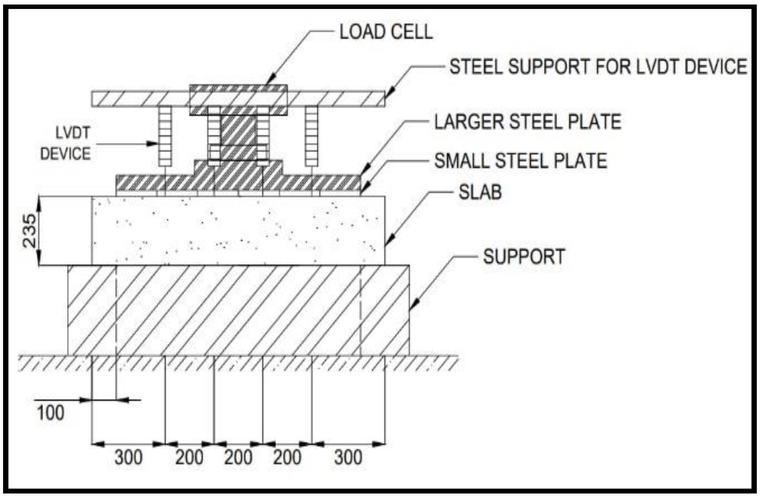


Figure 10. Schematic diagram of the area loading test

3. Results and discussions

From this study, three main results was discussed.

3.1. The load-deflections impact from area loading test

Figures 11 and 12 present the results of the load-deflection reading taking from the LVDT of the slab specimens; conventional reinforced concrete solid slab (SS) and reinforced concrete bubble deck slab (BD) subjected to area loading. Both figures show the increments in deflections at the five marked locations of LVDT (refer to Figure 8). Compared to the BD load-deflection to the SS load-deflection, the deflection values are higher. The same pattern was found in [16,17,18]. The maximum loading applied for both slabs is nearly the same with only two percent higher for the SS which is 471.328 kN but the BD display higher deflection. Moreover, the BD increments in deflections have an unsmooth pattern which can be indicated by the presented graph. Further investigation found that the BD reading taken during the flexural test was not stable. This could imply that the bubble balls in the BD slab reacted to the applied loading as BD is not as solid and compact as SS. As mentioned before, the bubble ball volume in the BD was more than 30%.

From [16 and 17], the load-deflection curves obtained with the area loading applied on both slabs (SS and BD) demonstrated smooth increasing deflection. Furthermore, the deflection movement was found in the same direction. However, the deflection occurring in this study has one point demonstrated in different directions which at near the support (please refer to Figure 8). From the inspection, the platform of the strong floor machine was uneven as some parts of the platform has a higher level compared to another one. This could affect the reading of the deflection during the test at each LVDT reader.

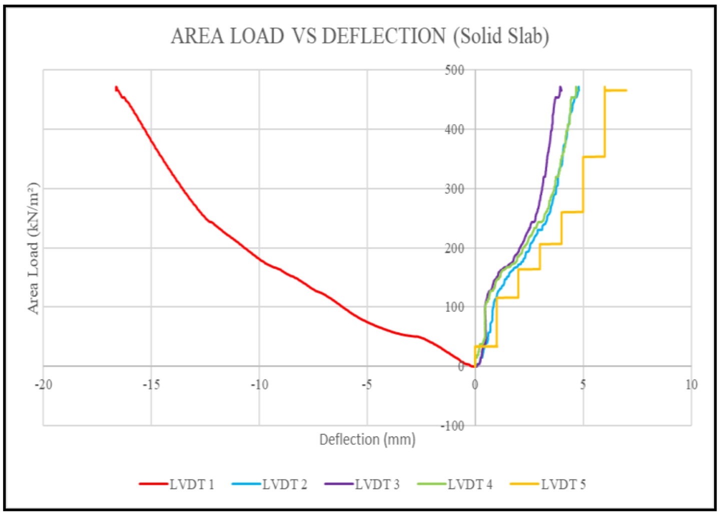


Figure 11. Area loading- deflection graph for conventional solid slab (SS)

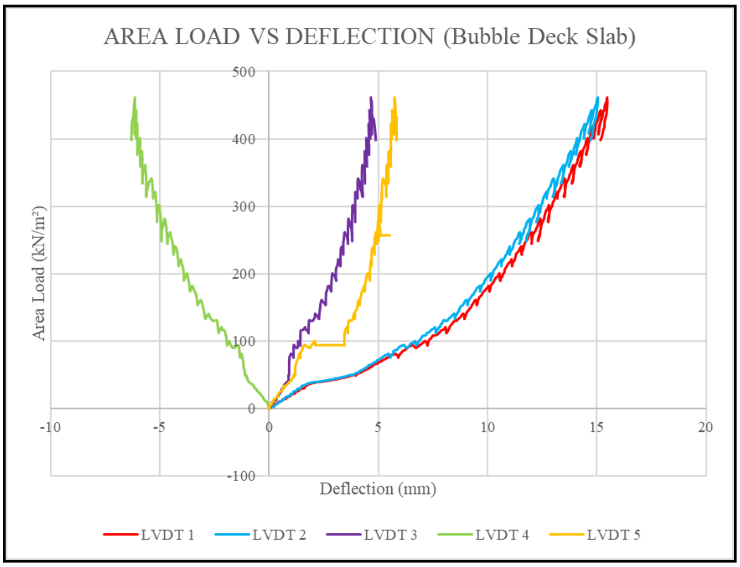


Figure 12. Area loading- deflection graph for bubble deck slab (BD)

3.2. Bending Stiffness

It is important to know the limiting value of the structure strength. Hence, by knowing the bending stiffness of the structure, the failure stress of the structure can be determined. This helps the designers and engineers to notice beforehand the mechanical properties of structural members and the limit load applied before proceeding to the construction. The bending stiffness can be calculated accordingly to Equation 1 and the values of this limit strength for both slabs, SS and BD are presented in Table 2.

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

Table 2. Bending stiffness of the conventional reinforced solid slab (SS) and bubble deck slab (BD)

Characteristic	Type of Slab	
	Conventional Slab (SS)	Bubble Deck Slab (BD)
Selfweight, s/w (kN/m^2)	5.750	1.768
Span length, L (m)	1.200	
Maximum area load, w (kN/m^2)	471.328	461.518
Maximum deflection, f_{max} (m)	6.000 x 10^{-3}	15.490 x 10^{-3}
Bending stiffness, EI (kNm^2)	2146.851	807.535
EI $_{bubble\ deck}$ / EI $_{solid\ slab}$	0.376	

The results given in Table 2 demonstrate that the SS has a 62.4 % higher resistance of bending stiffness compared to the BD. This indicates that the efficiency of the SS provides higher resistance in terms of elastic deformation compared to the BD. However, compared with [15], the bending stress of the BD was found to be 10% lesser than SS. This could be the different types of bubble balls that affected the stiffness of the reinforced concrete slab.

3.3. Crack pattern and its propagation

The first crack was observed at 140 kN at the conventional solid slab (SS) and 80 kN at the bubble deck slab (BD) respectively. Both initial and crack propagation was observed at 45º near the support. Figure 13 shows the propagation of the crack at the bottom of the slabs while Figure 14 present the development of the cracks propagating at both slabs at four different view elevation (refer to Figure 8).

View Side	Crack Pattern	
	Bubble Deck Slab (BD)	Conventional Solid Slab (SS)
Plan View		

Figure 13. The crack pattern of a bubble deck slab and a conventional slab subjected to area loading from the bottom view.

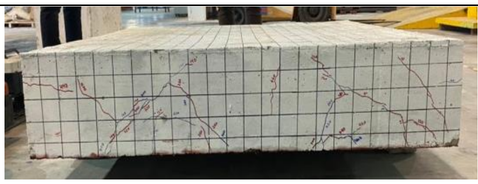
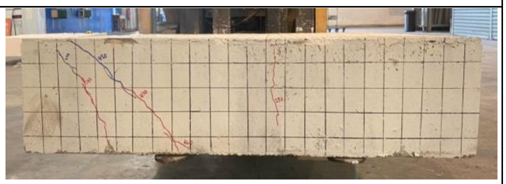
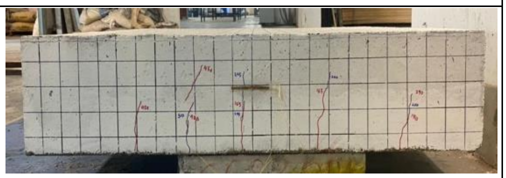
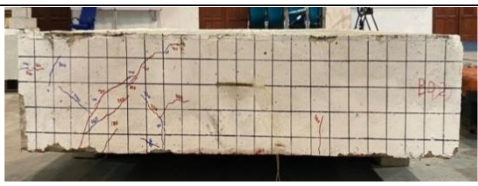
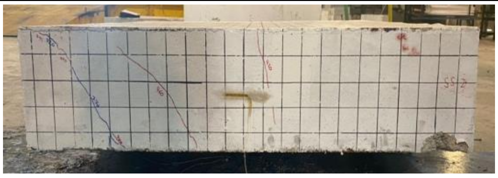
View Side	Crack Pattern	
	Bubble Deck Slab (BD)	Conventional Solid Slab (SS)
1		
2		
3		
4		

Figure 14. The crack pattern of a bubble deck slab and a conventional slab subjected to area loading at different elevations.

As there was increasing in bending stress at the slab's mid-span, the crack started to initiate when the load was 250 kN at the conventional reinforced concrete slab (SS). On the contrary, the crack begin to develop on the reinforced bubble deck slab (BD) when the load achieved 440 kN. However, compared to the SS, BD evolves more combination of cracks due to bending stress and shear. The bubble deck slab shows the shear cracks developed at 45º and 50º at the left and right portions of the slab.

At elevation 2, SS developed cracks as the increase of bending stress at the mid-span of the slab while BD developed cracks due to the combination of the action of bending stress and shear. The bubble deck slab shows the shear cracks angle measured with the load of 100kN was 45° at the right of the slab and some flexural cracks at the mid-span. While the SS have a fine line crack of the flexural cracks at the mid-span of the slab.

More shear cracks propagated were developed on BD at elevations 3 and 4 compared to SS at the same elevation view. The SS presents more flexural cracks in the overall slab which show that the SS can distribute the load more equally even compared to BD.

4. Conclusions

In this study, the conclusions that can be made are as follow:

- The two-way spanning of the reinforced concrete solid slab (SS) has a 62.39% higher resistance against bending deformation compared to the reinforced bubble deck (BD) slab when subjected to a uniformly distributed area load.
- The reinforced bubble deck slab (BD) spanning in a two-way direction has 0.396 in terms of stiffness ratio compared to the reinforced concrete solid slab (SS) that spans in the same direction.
- The two-way spanning reinforced bubble deck slab (BD) has a lower shear resistance as shear cracks propagate more frequently on the BD compared to the reinforced concrete solid slab (SS) that spans in the same direction.

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