PERFORMANCE
OF
BUBBLE DECK SLAB

LIEW MUN KAI

B. ENG (HONS.) CIVIL ENGINEERING

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Thesis submitted in fulfillment of the requirements
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ABSTRAK

Struktur slab dianggap sebagai salah satu struktur terbesar yang menggunakan sejumlah besar konkrit dalam pembinaan bangunan. Konkrit adalah bahan tunggal yang paling banyak digunakan di dunia. Malangnya, konkrit mempunyai masalah [6]. Bahan-bahan konkrit yang dicipta akan mencemarkan alam sekitar. Pada tahun 1990-an, Jorgen Bruenig telah mencipta slab berongga biaxial yang pertama yang dipanggil slab gelembung dek. Sistem slab gelembung dek bertindak sebagai kaedah praktikal membuang jumlah konkrit dari tengah-tengah slab lantai kerana tidak melaksanakan sebarang tujuan struktur [1]. Oleh itu, ia mengurangkan berat mati struktur secara dramatik kerana jumlah signifikan konkrit telah 'dipindahkan'. Kekosongan di tengah-tengah slab rata dipenuhi dengan sfera plastik yang membuang slab berat diri. Secara mengagumkan, penyingkiran berat badan slab kira-kira hasil sebanyak 35% dalam mengurangkan sekatan beban mati yang tinggi dan span yang pendek [9]. Jumlah kuantiti konkrit yang dikurangkan telah mengakibatkan penurunan pengeluaran karbon dioksida secara tidak langsung dan dengan menggunakan plastik kitar semula sebagai bahan pengganti alternatif untuk sistem konkrit gelembung dek boleh dianggap sebagai kaedah pembinaan slab yang menyumbang kepada teknologi hijau. Prestasi papak gelembung gelung ditentukan dengan perbandingan dibuat terhadap papak konvensional yang berdasarkan kekuatan lenturan, jenis kegagalan dan corak retak dan penyebaran. Spesimen yang digunakan ialah 1500mm dengan 1500mm untuk lebar dan panjang dengan ketebalan 285mm. Sebanyak 25 gelembung plastik HDPE berongga ketebalan 230mm telah digunakan untuk spesimen gelembung dek. Besi tetulang keluli yang digunakan ialah tebal 6mm keluli hasil ringan. Tambahan pula, sebanyak 12 kiub konkrit dimensi 150 kubik mm dengan gred konkrit 30 dibahagikan kepada 4 jenis masa pengawetan konkrit dengan 3 setiap satu iaitu 3 hari, 7 hari, 14 hari dan 28 hari sebelum ujian mampatan dilakukan. Selain itu, ujian tegangan telah dijalankan untuk menghasilkan keluli yang tinggi bersaiz 8mm dan 10mm manakala keluli ringan adalah 6mm, 8mm dan 10mm. Ujian fleksural dilakukan pada kedua-dua slab gelembung dek dan slab konvensional dengan menggunakan tiga ujian lenturan titik selepas pengawetan kedua-dua slab dalam air selama 28 hari. Daripada keputusan yang diperoleh, penurunan kekuatan ricih sebanyak 53% untuk slab gelembung dek manakala 36% untuk slab pepejal konvensional dengan kekuatan ricih reka bentuk 136.64 kN. Kekuatan lenturan slab gelembung dek adalah 447.51 MPa yang lebih rendah daripada slab konvensional, 608.09 MPa. Ia dapat disimpulkan bahawa slab gelembung dek dengan berat badan yang lebih rendah dan dimensi yang sama berbanding dengan papak pepejal konvensional mempunyai beban muktamad yang lebih tinggi daripada papak pepejal konvensional. Selain itu, pada beban puncak, retakan utama dan mikro retakan berlaku di tepi berhampiran pertengahan slab.

ABSTRACT

Slab structure is considered as one of the largest structural members that consumes large amount of concrete in a building construction. Concrete is the single most widely used material in the world. Unfortunately, concrete has a problem [6]. Concrete created substances that polluted the environment. In the 1990's, Jorgen Bruenig had invented the first biaxial voided slab called bubble deck slab. Bubble deck slab system acts as a method of practically removing the concrete volume from the middle of a floor slab for not performing any structural purpose [1]. Thereby it reduces the structural dead weight dramatically as significant amount of concrete volume has been 'evacuated'. The voids in the middle of a flat slab are filled with plastic spheres that remove the self-weight of slab. Impressively, the removal of self-weight of the slab approximately result by 35% in removing the restriction of high dead loads and short spans [9]. The reduced amount of concrete volume has led to the decreasing production of carbon dioxide indirectly and by using recycled plastic as an alternative replacement material for concrete, bubble deck slab system can be considered as a slab construction method that contributes to green technology. The performance of bubble deck slab was determined with comparisons being made against the conventional solid slab which was based on the flexural strength, type of failures and the crack pattern and propagation. The specimens used were 1500mm by 1500mm for width and length with a thickness of 285mm. A total of 25 HDPE hollow plastic bubble balls of thickness 230mm were used for the bubble deck slab specimen. The reinforcement steel bar meshes used were 6mm thick of mild yield steel. Furthermore, a total of 12 concrete cubes of dimensions 150 cubic mm with concrete grade 30 were divided into 4 kinds of concrete curing periods with 3 each which were 3 days, 7 days, 14 days and 28 days before compression test was conducted. Apart from that, tensile test was carried out for high yield steel size 8mm and 10mm while mild steel are 6mm, 8mm and 10mm. Flexural test was done on both the bubble deck slab and conventional solid slab by the application of three point flexural testing after both slabs were cured by water for a total of 28 days. From the results obtained, the percentage drop of shear strength was 53% for bubble deck slab whilst 36% for conventional solid slab with comparison with design shear strength of 136.64 kN. The modulus of rupture of bubble deck slab was 447.51 MPa which was lower than conventional slab, 608.09 MPa. It can be concluded that bubble deck slab with lower self-weight and same dimensions as compared to conventional solid slab has a higher ultimate load than conventional solid slab. Moreover, at peak load, microcracking occurred at the sides near the middle of the slab.

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LIST OF SYMBOLS

^{o}c	Degree Celsius
E	Modulus of Elasticity
kN	Kilo Newton
mm	Millimetre
m	Metre
%	Percentage
kN/mm^2	Kilo Newton per millimetre square

LIST OF ABBREVIATIONS

HDPE	High Density Polyethylene
BD	BubbleDeck
OPC	Ordinary Portland Cement
UTM	Universal Testing Machine
LVDT	Linear Variable Differential Transformer
Eq.	Equation
et al	*et alia*

CHAPTER 1

INTRODUCTION

1.1 History Background

Slab structure is considered as one of the largest structural members that consumes large amount of concrete in a building construction (Bhade & Barelikar, 2016). Since it requires a big amount of concrete volume, it has to be designed in appropriate way. According to Bhade and Barelikar (2016), the deflection of the slab structure tends to increase as the concentrated load acting on the slab is great which leads to the expanding of slab thickness. The high thickness of slabs will create a heavier slab due to the increasing of self-weight of and also the size of column and foundations. In conclusion, the increase of size of structure members such as the beam and column will generally increase the total amount of materials used and consequently the cost increases as well.

In the mid-20th Century, the voided or hollow core floor system was created to reduce the high weight-to-strength ratio of typical concrete systems. This concept removes or replaces concrete from the centre of the slab, where it is less useful, with a lighter material in order to decrease the dead weight of the concrete floor. However, these hollow cavities significantly decrease the slabs resistance to shear and fire, thus reducing its structural integrity (Lai, 2010). Thus, there is a numerous number of researches continue to perform and conduct tests in order to overcome this problem especially to the design engineers in order to reduce the weight of the slab structure without affecting the structural integrity.

In the 1990’s, Jorgen Bruenig had invented the first biaxial voided slab called bubble deck slab (Mirajkar *et al*, 2017). Bubble deck slab system acts as a method of practically removing the concrete volume from the middle of a floor slab for not performing any structural purpose as shown in Figure 1.1. Thereby it reduces the structural dead weight dramatically as significant amount of concrete volume has been 'evacuated'. Bubble deck slab is based on an established technique which involves the relationship between air and reinforcement steel bars. The voids in the middle of a flat slab are filled with plastic spheres that remove the self-weight of slab. Impressively, the removal of selfweight of the slab approximately result by 35% in removing the restriction of high dead loads and short spans (Teja *et al*., 2012).

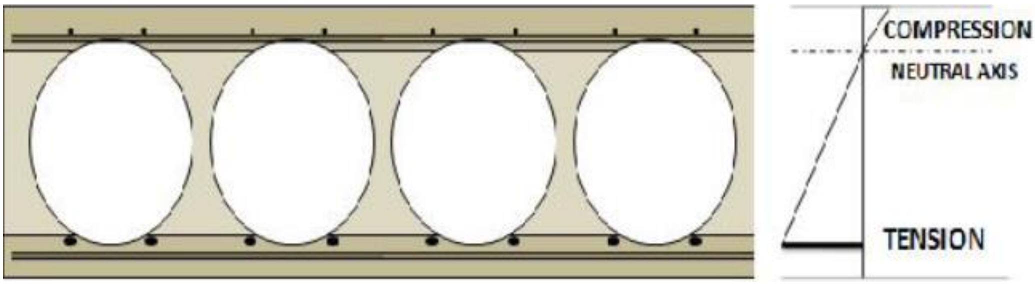

Figure 1.1 Stress diagram of bubble deck slab
Source: Teja *et al*. (2012)

Slab thickness can be reduced since the weight of the slab structure has greatly reduced. The lower weight or slab structural members results in lower load transfer to columns and ultimately the foundations. In other words, columns and foundations can be designed in smaller sized which also mean the overall construction costs can be reduced. Bubble deck slab, without the necessity of formwork practically, no support beams. In additiona, the fabrication of slab structures is roughly 20% faster than the method of conventional regardless of shape, complexity or the project size (Joseph, 2016).

The bubble deck creates void area of air between concrete layers top and bottom with reinforcement steel meshes and the load distribution across the plastic spheres. Bubble deck is a new innovative slab system that might not see any major differences in a building's construction at the beginning but in a –situ casting, the application of Bubble deck technology gives many significant differences.

The bubble deck system offers a wide range of advantages in building design and during construction. Numerous attributes that will consider the system as green technology are the usage of recycled materials such as the plastic spheres, the reduction of construction materials and energy consumption, the reduced amount of concrete, less transportation and less utilization of heavy machinery and crane lifts that make bubble deck a more environmentally friendly than other slab construction system techniques. According to Joseph (2016), bubble deck can achieve larger and longer spans as compared to a site cast concrete structure without the necessity for pre-stressing or post-tensioning components through the removal of ineffective concrete and replacing it with plastic spheres that greatly reduce the dead load of the structure. Through the method of prefabrication and in-situ casting, the total construction time for the structural members was reduced which allowed the design engineers to accelerate the design. The contractor is estimated to set roughly 5574 m^2 in a month and allowed the completion of concrete structure before the fall classes even started (Joseph, 2016).

1.2 Problem Statement

Concrete is the single most widely used material in the world. Unfortunately, concrete has a problem. Concrete has condemned through its application in innumerable architectural eyesores, from carparks to tower blocks, concrete's environmental credentials are now coming under scrutiny. The material is utilized globally that the production of cement worldwide now contributes 5 per cent of annual global carbon dioxide production, with China's booming construction industry producing 3 per cent alone (Crow, 2008). The problem is estimated to get worse where it has produced over 19.93 Tera Newton in quantity per year, it is predicted that the concrete use is to reach four times the 1990 level by 2050.

In a concrete slab structure, not all parts of the structural member are of maximum usefulness (Joseph, 2016). The central portion of the reinforced cement concrete solid slab is an inactive concrete as shown in Figure 1.2. The spacer between the bottom, where the reinforcing steel is in tension, and the top, where the concrete is in compression is inactive due to the lack of force. It would be a waste of concrete if the spacer is to be filled up with concrete. Concrete is heavy and it increases the dead loads of the structure. The spacer can be removed and replaced with lighter materials such as the plastic bubble spheres used in bubble deck slab. By using this way, it can decrease the dead load by reducing the concrete volume. The reduced amount of concrete volume has led to the decreasing production of carbon dioxide indirectly and by using recycled plastic as an alternative replacement material for concrete, bubble deck slab system can be considered as a slab construction method that contributes to green technology.

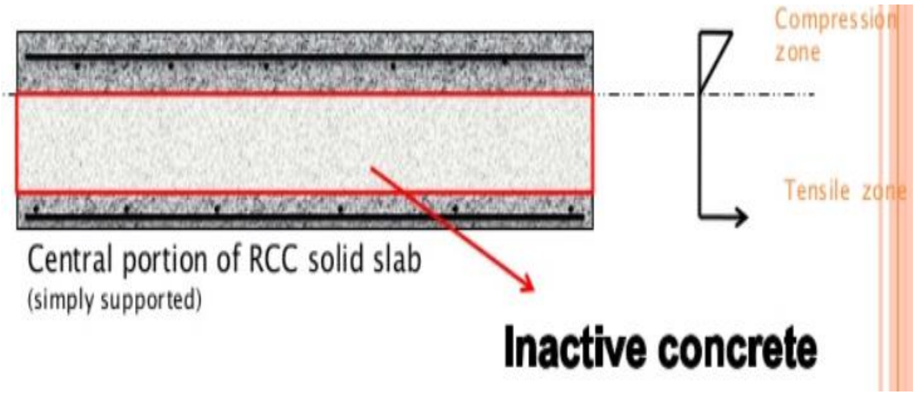

Figure 1.2 Inactive concrete in the spacer

Source: BubbleDeck International (2014).

Bubble deck is a new technology system but not everyone is aware of that. As a new technology, it looks unconvincing for the industries to truly utilize it. The industry lacks confidence in using it and it seems risky for them to attempt and operate new projects with the new technology. The industry also prefers to follow the traditional method as it is the safest and well-known method without realizing that bubble deck has its own advantages as they lack knowledge on the new technology. Bubble deck system needs to be proven with its quality and advantages so the industry has the confidence in using the new method and it could revolutionize the construction industries with the finer method and move towards the green concept.

1.3 Objective

The purpose of this study is to investigate the alternative slab construction method, the bubble deck system that gives improvement to conventional slab system and comparisons are being made between the two slab systems. The objectives of this study include:

a) To compare the flexural strength of bubble deck slab and solid slab
b) To determine the failure of bubble deck slab and solid slab
c) To observe the crack pattern and propagation on bubble deck slab and solid slab after flexural tests have performed

1.4 Scope of Study

The study focuses on the new technology bubble deck on the application of slab constructions based on the flexural strength of the structure and to observe the crack pattern on both deck system; solid and bubble deck. For this investigation, the comparison tests will be studied and experimented in order to gain a better understanding of the new technique and to compare it with the conventional slab system.

Bubble deck is composed of three main materials which are steel, plastic spheres and concrete, as seen in Figure 1.3.

- Steel – The steel reinforcement used is mild steel. The steel is fabricated in two forms which are meshed layers for lateral support and diagonal girders for vertical support of the bubbles
- Plastic spheres – The hollow spheres are made from recycled high-density polyethylene or HDPE
- Concrete – The concrete is made of standard Portland cement with a maximum aggregate size three quarter inch. No plasticizers are necessary for the concrete mixture. (BubbleDeck International)

Figure 1.3 Components of a bubble deck slab

Source: Joseph (2016)

Several laboratory tests will be conducted in my research. The flexural test will be experimented on both bubble deck slab and conventional solid slab to determine the modulus of rupture acted on them and the effects. Concrete cubes compression tests will be carried out before the experiment begins to obtain the strength of concrete.

The total amount of reinforcement bars used for each slab system will be obtained and further including the total quantity of concrete and materials used in obtaining the overall cost for both slab systems. Furthermore, the total time taken for the concrete to achieve minimum compressive strength for both slab systems will be recorded as in determining which slab system is the faster method of fabrication. Lastly, the crack pattern and failure mode will be studied during the testing of flexural on both the slab systems.

1.5 Significance of Study

This study concerns on reusing of natural resources to reduce environmental pollution. Several aspects need to be signified in the study. Firstly, it is vital to consider the environmental issue. The number of people ranging from designer to contractor and then to customers that desire green technology is increasing and expanding. Bubble deck is an ideal solution for reducing the amount of carbon in new buildings. According to the BubbleDeck International (2014), 1 kg of recycled plastic replaces 100 kg of concrete . The dead load of the structural member can be reduced greatly which allows the design engineers to design the slab structure in a more economical way by reducing the sizes of reinforcements and thickness of the slab. The decreased dead load of the slab structure requires a lower quantity of concrete and consequently it decreases the amount of concrete transportation. It also reduces the utilization of heavy machinery which eventually the cost of the project will also decrease. Additionally, the HDPE bubbles can be salvaged and reused and recycled for further usage in other projects.

In engineering point of view, bubble deck can reduce the overall weight of the structure and increase the strength of the slab with fewer columns and foundations due to the lighter slabs and lower value of a dead load of the whole structure. Bubble deck provides less deflection for long spans. Moreover, bubble deck is a prefabricated method and applies in-situ casting which it has no obvious joins and connections after the casting is completed. Hence, there will be no leakage through connections and problem such as trapped water in hollow canals will not be discovered (Joseph, 2016).

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Reviews of previous research works on bubble deck slab are presented in this chapter. Considering the objectives of this study were to determine the flexural strength of bubble deck slab and the failure or crack patterns for bubble deck slab and solid slab after load capacity test. Comparisons are being made between the two slab systems.

2.2 Materials

The materials are designed, measured and obtained in accordance with Eurocode 2 and BS8110.

2.2.1 Concrete

Standard Portland cement is used as one of the components in fabricating into concrete with 20 mm as the maximum aggregate size. Plasticizers are not required in the concrete mixing compound. According to Călin, Gînţu, & Dascălu (2009), numerous tests have proven that the characteristic compressive strength of concrete of bubble deck slabs has the same results and standard as that of solid slabs.

2.2.2 Steel

Reinforcement mild steel bar yield strength 275 N/mm^2 or higher are used. The rebar mesh is erected over and below the HDPE plastic balls. Therefore, the plastic balls can be placed without any significant movement. A correct placement and orientation of bubbles are possible through placing and locking of them in the reinforcement bars. Additional requiring of shear bars is provided and the majority of the shear bars are added near the columns.

2.2.3 Plastic Hollow Spheres

The voided spheres which are referred as ‘bubbles’ are made from recycled high-density polyethylene or HDPE. There are different sizes of bubbles obtainable which depend on the size of the structure. These bubbles are environmentally friendly. In other words, they can be recycled and reused which have contributed to one of the green properties of the bubble deck slab. Table 2.1 shows the different types of plastic bubbles available in market and Table 2.2 shows the properties of materials.

Figure 2.1 Plastic spheres along with reinforcement

Source: Joseph (2016)

Table 2.1 Different versions of plastic bubbles available in market

Version	**Slab thickness, mm**	**Bubbles diameter, mm**	**Cantilever-maximum length m**	**Span, m**	**Completed slab mass, KN/m^2**	**Site concrete quantity m^3/m^2**
BD230	230	180	<=2.8	5-6.5	4.26	0.112
BD280	280	225	<=3.3	6-7.8	5.11	0.146
BD340	340	270	<=4.0	7-9.5	6.22	0.191
BD390	390	315	<=4.7	9-10.9	6.92	0.219
BD450	450	360	<=5.4	10-12.5	7.85	0.252
BD510	510	410	<=6.1	11-13.9	9.09	0.298
BD600	600	500	<=7.2	12-15.0	10.30	0.348

Source: Joseph (2016).

Table 2.2 Properties of materials

Name of Material	Parameter	Value
Steel	Modulus of Elasticity (E)	200000 Mpa
	Density	7850 Kg/m^3
	Poisson's Ratio	0.3
Concrete	Modulus of Elasticity (E)	25000 Mpa
	Density	2460 Kg/m^3
	Poisson's Ratio	0.18
Plastic HDPE	Modulus of Elasticity (E)	1035 Mpa
	Density	970 Kg/m^3
	Poisson's Ratio	0.4
Safety Characteristics	Decomposition temperature	>300^{o}c
	Flashpoint	>355^{o}c

Source: Ali & Manoj Kumar (2017)

2.3 High Density Polyethylene or HDPE

HDPE is known as one of the world's most popular plastics. It is an enormously versatile polymer which is suited to a wide range of applications from the heavy-duty damp proof membrane for new buildings to light, flexible bags and films.

2.3.1 History of HDPE

Near to 19th century, there is a German chemist named Hans von Pechmann has recorded a precipitate during the reaction in ether from the form of methane (Gabriel, 1998). In 1998, Gabriel reported that there are another two German chemists named Friedrich Tschirner and Eugen Bamberger successfully identified the precipitation as polymethylene, a very close relationship with polyethylene in 1900.

Gabriel documented that the British chemists Reginald Gibson and Eric Fawcett had produced a concrete form of polyethylene in 1935. The first commercial application was insulation of radar cables during the World War II. The invention of high density polyethylene (HDPE) was by Erhard Holzkamp and Karl Ziegler from the Institute of Kaiser Wilhelm. The process of invention included the basis of formulation which was the use of catalysts and low pressure for numerous types of polyethylene compounds. Since then, the pipe was produced by using HDPE two years later. Due to the hard works contributed Ziegler, the 1963 Nobel Prize for Chemistry was awarded to him.

Pipes made of plastic materials are graded under thermosetting, a synthetic material that strengthens after being heated but it loses the ability to be remoulded or in another term, thermoplastic (Gabriel, 1998). Drainage pipes in highway made of thermoplastic had been used since the early 1970s. This kind of pipe displays good qualities like flexibility, resistivity against chemical, electrical insulation. After the introduction of HDPE, the number of applications on piping services had rocketed to a certain level which they covered drainage pipes, storm drains, cross drains, culverts, storm sewers and drains.

Other than that, Zaki *et al. (*2017) stated that the importance of polymeric materials has increased very rapidly during the last few decades which have widespread application due to their many-sided characteristics, highly tailored production and cost-effectiveness, and it is useful in many fields, such as engineering technology, defense supplies, and medical devices. One of these materials is high-density polyethylene, which has distinctive characteristics, such as low cost, low weight, easy fabrication with different thicknesses, easy processability, high chemical resistance, mechanical properties and excellent biocompatibility.

2.3.2 Physical Chemistry and Mechanical Properties of HDPE

In 1998, Gabriel reported and concluded that HDPE of density is between 0.941 and 0.965 is a thermoplastic material composed of the combination of carbon and hydrogen atoms forming high molecular weight products as shown in Figure 2.3. Figure 2.2 shows methane gas is converted into ethylene in Figure 2.3. After application of heat and pressure, ethylene will be converted into polyethylene in Figure 2.4.

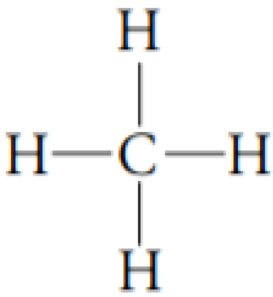

Figure 2.2 Methane
Source: Gabriel (1998)

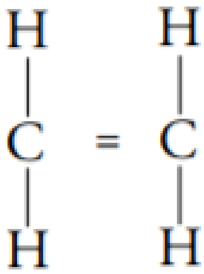

Figure 2.3 Ethylene
Source: Gabriel (1998)

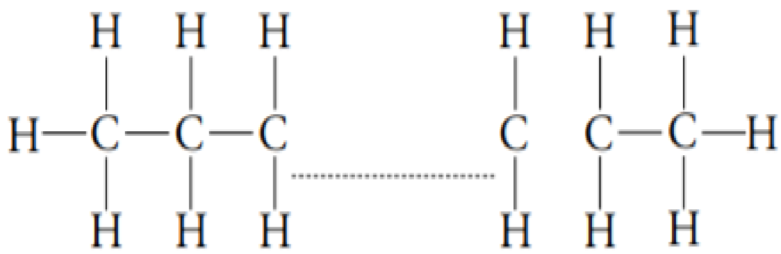

Figure 2.4 Polyethylene molecular chain

Source: Gabriel (1998)

The polymer chain may consist of 500,000 to 1,000,000 carbon units long. Short or long side chain molecules exist with the polymer's long main chain molecules. The longer the main chain, the greater the number of HDPE atoms, and consequently, the greater the molecular weight. The molecular weight, the molecular weight distribution and the amount of branching determine many of the mechanical and chemical properties of the end product.

Table 2.3 Mechanical and chemical property of (HDPE) spheres

Formulation detail about ingredients	
Chemical designation	High Density Polyethylene (HDPE)
Usual chemical designation	High Density Polyethylene (HDPE)
Chemical formulation	$(-CH_2CH_2)_n$
Genus	Polyolefin
Hazardous additional substances	None
Physical and chemical property	
Physical condition	Solid at 20 °C
Tensile strength	0.20-0.40 N/mm^2
Colour	Chosen by manufacturer
pH	Not applicable
Relative density	940-965 kg/m^3
Melting point	127-137 °C
Softing point	123-124 °C
Solubility in water	Insoluble

Source: Tiwari & Zafar (2016).

According to Gabriel (1998), polyethylene can be distinguished as a semi-translucent polymer, made up of formless regions and translucent regions. Translucent regions can be described as layered, precisely folded, highly ordered and heavily packed molecular chains. All of these will only occur when the branching off of chains off the primary chains are of non-significant numbers. In the translucent regions, the properties of the molecules are directly dependent onto each other. A large quantity of adjacently bundled polymer chains produce a strong material with average stiffness.

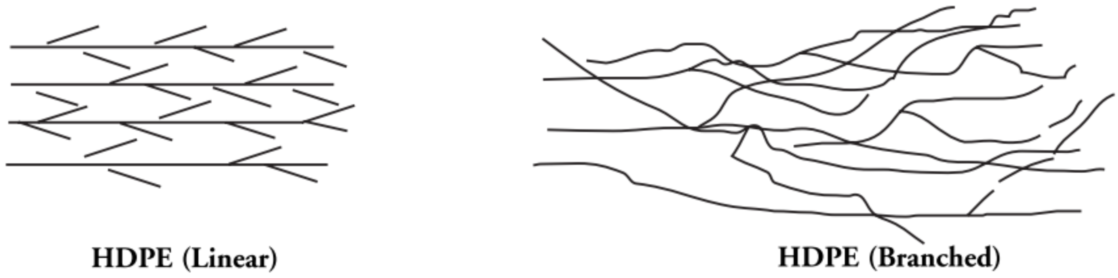

Figure 2.5 Diagrammatic of linear and branched arrangements

Source: Gabriel (1998)

During the process of development, the increased temperatures that were energy linked with the structural formation of the polyethylene have created random directions and placements of molecules inside the molten substance to be exactly arranged and aligned in the extruding vent. The properly aligned layered translucent polyethylene molecules are kept preserved. Formless and translucent regions are associated by tie molecules. The polymer will alter its own shape when the volume of polymer chains are overloaded with tension which will lead to cracking.

2.3.3 Advantages of HDPE

The HDPE bubbles replace the non-effective concrete in the centre spacer of the section, thus reducing the dead load and increasing the efficiency of the structure. Concrete use has decreased which leads to the reduction in the amount of structural steel as the necessity for reinforcement declines. The size of the foundations of the structure will be lower as the dead loads of the building have decreased. Hence, lighter floor slabs and smaller dead loads can be engineered into smaller size components and thus the cost of the project will be lower as well (Lai, 2010). From the report of Agarwal & Gupta (2011), one of the dominant advantages of utilizing of plastic material in buildings and construction is their ability to be formed into complex shapes. Furthermore, features like low cost and low maintenance, the availability in wide range of shapes and forms and durability are also the advantages.

2.4 Basic Principle of Schematic Design

According to Lai (2010), bubble deck is aimed to be a flat, two-way spanning slab supported directly by components such as columns. The design of the slab system is mainly adjusted by the maximum allowable deflection during service loading. The dimensions are controlled by the span (L) to effective depth (d) ratio (L/d) as stated by BS8110 or EC2. This standard can be altered by trying a factor of 1.5 regarding the greatly reduced dead weight of the bubble deck slab as compared to a conventional solid slab. In addition, post-tensioning slabs can aid in achieving larger spans as the L/d ratio can be extended up to 30%.

L/d < 30 for simply supported, single spans
L/d < 41 for continuously supported, multiple spans
L/d < 10.5 for cantilevers

Five customary thicknesses for bubble deck are thicknesses that vary from 230 mm to 450mm, and up to 510 mm and 600 mm for specific designs. Different types of bubble deck can be seen in Table 2.4.

Table 2.4 Various versions of Bubble Deck

Version	Bubble Diameter (mm)	Minimum Slab Thickness (mm)	Minimum Centre-to Centre Spacing (mm)
BD230	180	230	200
BD280	225	280	250
BD340	270	340	300
BD390	315	390	350
BD450	360	450	400
BD510	405	510	450
BD600	450	600	500

Source: Lai (2010).

2.5 Fire Resistance

The effective depth of a Bubble Deck slab is the overall depth less standard 20mm concrete cover from the bottom mesh reinforcement to the underside of the slab (Teja *et al*, 2012). Teja *et al* (2012) also stated that where 90 minutes of fire resistance is required to the slab depth off with overall 25mm while for 120 minutes of fire resistance, 30mm off of overall slab depth. In the case of spanning onto columns without beams use the longest dimensions between columns, where the slab will span onto walls or beams use the shortest span dimension.

According to Teja *et al.* (2012), the complexity of fire resistance in a slab is indeed true but it mainly depends on the capability of the reinforcement steel bars to maintain adequate strength in or during fire where the fire heats the slab too much higher temperatures where it loses its prime strength. The concrete somehow cracked and this has led to air escaping from concrete and the pressure in it dissipating. If HDPE plastic bubble balls are used, combustion has relatively nothing harm to the bubbles, assuredly compared to the surrounding materials that would be burning at the same time. In a much prolonged combustion, the bubbles are scorched until the surface of the bubbles are darken and eventually melted without any vital noticeable effect. In 2012, Teja *et al*. reported that fire resistance is dependent on the cover of concrete and it can last an approximate 60 to 180 minutes. For smoke resistivity, the height of the smokeless region is about 10m on either of the sides. The combusted bubbles are carbonized but no toxic gasses that will be released providentially.

2.6 Types of Bubble Deck

In 2016, Joseph reported that for all the various types of bubble deck, there consist of three forms which are filigree elements, reinforcement modules and finished planks. They are portrayed in Figure 2.5. For all types of bubble deck, the maximum element size for transportation purposes is 3m. There is no any difference in the capacity once the components are joined and attached.

2.6.1 Type A - Filigree Elements

Bubble deck type A consists of fabricated and unconstructed elements. In 2010, Tina Lai reported that the formwork and a fraction of the final depth which both of them are of 60mm thick are precast and brought to the site with the steel reinforcement and bubbles maintain unattached. Temporary stands are used as a support to the bubble balls on top of the precast layer and maintained in place by interlinked steel mesh. The general slab thickness is attained along with standard concrete techniques.

2.6.2 Type B - Reinforcement Modules

Type B is a reinforcement measurement that embodies the unconstructed and pre-assemble of bubbles and steel mesh. In another word, it can be called as bubble lattice. The working procedure is by bringing the components to the construction site, laying on formwork, connecting to other additional formwork and then finally with the pouring of concrete by using traditional methods. Type B bubble deck is favourable and ideal for building construction areas with limited spaces as the reinforcement modules, the bubble decks, are stackable to one another until when it is needed (Joseph, 2016).

2.6.3 Type C - Finished Planks

Type C is a shop fabrication module. Materials and components like the plastic spheres, concrete and steel mesh are ordered outside of the site and prepared a completed fabrication. Finished depth is being manufactured in the form of a floorboard before delivering to the construction site. Type C differs much from type A and type B in a way that it not a two way spanning design and it needs the use of load bearing walls or support beams. Type C bubble deck slab system is ideal for shorter spans and construction with tight and limited schedules (Joseph, 2016).

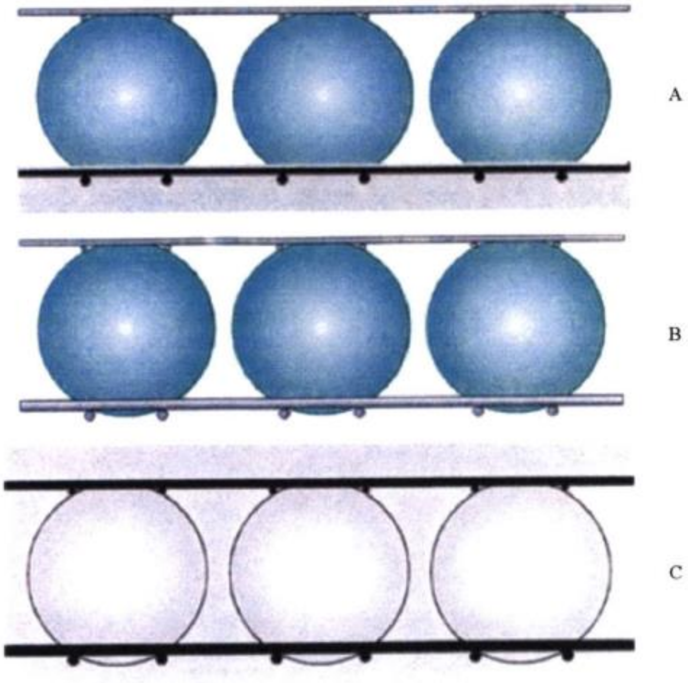

Figure 2.6 Three types of bubble deck - Type A, B & C

Source: Lai (2010).

2.7 Advantages of Bubble Deck

Bubble deck provides an extraordinary degree of freedom in architectural design choice of shape, large cantilevers, larger spans or deck areas with fewer supporting points with no beams, fewer columns and carrying walls results in flexible and easy changeable buildings. Interior design can easily be altered throughout the buildings lifetime (BubbleDeck International, 2014).

2.7.1 Material and Weight Reduction

The major advantage of using bubble deck slab is the low requirement of concrete volume with 30-50% less than conventional solid slabs (Lai, 2010). The main reason of this is due to the replacement of non-effective concrete in the spacer at the centre of the slab section by HPDE plastic bubble balls which it has directly decreased the dead load of the building structure. The lower volume of concrete of the structure has reduced the amount and size of reinforcement steel bars due to the lower dead load of the whole structure. The lower dead load of structure allow the design of smaller foundations. It is to conclude that the lighter the slabs, the lower the structural design requirements for the downstream components.

2.7.2 Construction and Time Saving

Bubble deck slab system can be very convenient and time-saving. Bubble deck can be completely constructed off site before being transported to the construction site to be installed directly. Installation of bubble deck on site does not take long time as the support beams are not required and only plane formwork will be required. The reinforcement bars of less diameter meshing be easily bound. The lack of load bearing walls and support beams has produced a fast erection of walls, columns which then lead to a short time of installations and constructions. More time will be saved as the lower volume of concrete allows a lower curing duration (Vakil & Madhuri Nilesh, 2017).

2.7.3 Cost Saving

Other than time saving, the bubble deck system can be cost-effective too. The reduced amount of materials and a dead load of structure leads to the reduction of transportation costs and the utilization of heavy machineries. Labour costs will be reduced as well as on-site construction has lowered through off-site of semi-fabricated bubble deck slab. Furthermore, lower dead load of the structure will be economical in structural designs due to the lower requirements in design criteria of the building structure. Although there is an increase of cost in prefabrication of slab structure off-site, however, the savings from construction time, building materials, transportations, utilization of heavy machineries and labour costs will offset the prefabrication cost of the slab structures.

2.7.4 Green Design

The climate change is becoming realistic nowadays. This has led to many people including the designers and engineers into considering and desiring green alternatives in any construction especially in building construction. Bubble deck is one of the many green alternatives as this slab system is able to decrease the production of carbon into the atmosphere simply by reducing the amount of concrete use by replacing it with HDPE plastic bubbles in new buildings. According to the company of bubble deck, 1 kg of recycled plastic replaces 100 kg of concrete. These bubbles can help to reduce up to 40% carbon embodied in the concrete slab with less concrete which also lower several of the structural design requirements for the downstream components such as the columns and foundations (Vakil & Madhuri Nilesh, 2017). Reduction of transportation and the usage of heavy machinery and equipment will also reduce the emission of carbon. In addition, the HDPE plastic bubbles balls can be destroyed, reused and even recycled for further usage in another project.

For an approximately 5,000 m^2 of bubble deck slab sample, it can save up a very impressive amount of materials and costs which are listed as below (Lai, 2010).

- 166 lorry trips of ready mix concrete
- 1000 m^3 of concrete in volume on site
- 1,798 Tonnes of foundation loads or 19 lesser piles
- 1,745 GJ of energy used in haulage of concrete and production
- 278 Tonnes of carbon dioxide, the emissions of greenhouse gases

2.8 Structural Properties

Load bearing walls have become unnecessary due to the reduced dead load of the slab and its two way spanning actions. In some occasions, flat slabs are designed using the concept of bubble deck that removes the necessity of girder members and support beams (Vakil & Madhuri Nilesh, 2017). These characteristics lower several of the structural design requirements for the downstream components such as the columns and foundations. In additional, the design of bubble deck slab can be compared and analysed with the conventional solid slab based on the results of the research on properties such as the strength and ductility. The comparisons between bubble deck slab and standard solid slab based on carrying capacity and dead load are shown in Table 2.5 below.

Table 2.5 Carrying capacity and dead loads of bubble deck and solid slab

Relative % of solid slab	Solid Slab	Bubble deck® with the same thickness	Bubble deck® with the same capacity
Carrying Capacity	25	50	25
Dead Load	75	50	40
Dead Load to Carrying Capacity Ratio	3:01	1:01	1.5:1

Source: Lai (2010)

Research and tests have been carried out at numerous institutions in Germany, Netherlands and Denmark on the structural and mechanical behaviour of bubble deck (Călin, Gînţu, & Dascălu, 2009). The studies are mainly on deflection, bending strength, punching shear, bending strength, sound testing and fire resistance. The design code was based on Eurocode as all the available studies took place in European countries.

2.8.1 Technical Certifications

Călin *et al*. (2009) detailed numerous European authorities as listed below have certified bubble deck.

- The Denmark. Slab could be designed with bubble deck slab system according to the present standards and principles as mentioned by the

Directorate of Building and Housing from the Municipality of Copenhagen.

- The United Kingdom. In 1997, the involvement of bubble deck slab system in British standard BS8110 as a standard flat and biaxial voided slab with support from columns was accepted and approved by the Concrete Research & Innovation Centre (CRIC).
- The Netherlands. Civieltechnisch Centrum Uitvoering Research en Regelgeving (CUR) Committee 86 had integrated and merged bubble deck slab system into NEN 6720, the Dutch standards in 2001. In addition, Kiwa N.V., an official European Corporation for Technical Approvals (EOTA) member awarded the KOMO Certificate K22722/01 for the success and contribution of Bubble deck in 2002.
- The Germany. Bubble deck as the new slab system could be applied to the construction buildings with the present standards, principles and codes. It was acknowledged in the Bubble deck Engineering Design & Properties Overview, DIN 1045 and was recognized by the Deutsches Institut fur Bautechnik.

2.8.2 Bending Stiffness and Deflection

Lai (2010) stated that the contribution to bending in term of flexural stiffness is only from two major parts of slab structure, the bottom reinforcement steel bars of a solid concrete slab and the compressive part at top. A standard simplified rectangular beam stress block is shown in Figure 2.7. The design of the slab is based on Eurocode 2 and British Standard BS8110. The zone where include the bubbles or HDPE is squeezed between layers of concrete of roughly equivalent stress block thickness of that from the solid slab. Nevertheless, several laboratory tests have demonstrated that anything that is up to a 20% intrusion experiences an insignificant effect on the operation and performance of the bubble deck (Lai, 2010).

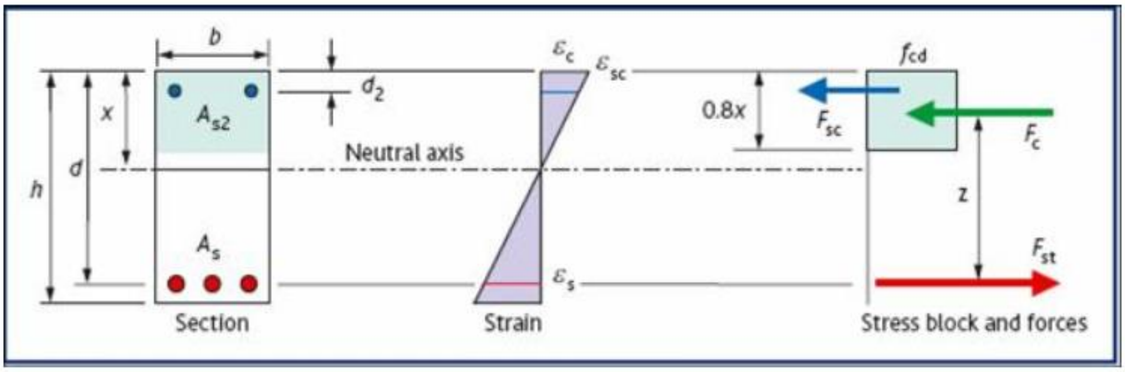

Figure 2.7 Standard rectangular stress block

Source: Eurocode 2

2.8.2.1 Approved Research

In 2010, Lai stated that the Technical University of Delft and The Eindhoven University of Technology in the Netherlands have conducted numerous experiments that focused on the bending stiffness of slabs constructed by bubble deck system. They concentrated on the available slab thicknesses 230 mm and 455 mm which are the smallest and largest depths respectively. The investigators discovered that bubble deck has identical flexural to that of the conventional solid concrete slab, theoretically and practically.

Numerous tests were performed on the bending stiffness of a bubble deck slab by the Technical University of Darmstadt in Germany. The results were confirmed by the physical tests and a theoretical study conducted in the Netherlands. From the results obtained, bubble deck had an impressive 87% of the bending stiffness of identical dimensions of the slab with conventional solid concrete slab but merely 66% of the concrete volume was required due to the replacement of concrete spacer by HDPE plastic bubbles. Consequently, the deflection of bubble deck slab was slightly higher compared to a solid slab. Nevertheless, the remarkably lower level of dead weight reimbursed for the marginally decreased in stiffness. Thus, bubble deck has a higher carrying capacity than a solid slab. Table 2.6 summarizes the stiffness comparison based on their findings from experimental results.

Table 2.6 Stiffness comparison

(in % of solid the slab)	Same Strength	Same Bending Stiffness	Same Concrete Volume
Strength	100	105	150
Bending Stiffness	87	100	300
Volume of Concrete	66	69	100

Source: Călin *et al*. (2009)

According to Lai (2010), surveys and studies have also validated that the deflections under service loads were a slightly higher than of similar and equivalent solid slab. In addition, serviceability limit state design has a long term positive influence due to the decreased dead load which is it can control the spreading of cracks.

2.8.3 Shear Strength

In 2010, Lai also stated that the effective mass of concrete greatly affects the shear strength of any concrete slab. The significant reduction in shear resistance of a bubble deck slab is due to the introduction of HDPE plastic bubbles. Theoretical models have shown that the shear strength of the hollow biaxial slab was discovered to be 60% to 80% to a conventional solid flat slab of the same thickness. Hence, the shear capacity of all bubble deck slabs has to apply a reduction factor which is 0.6 (Lai, 2010). Lai also mentioned shear resistance is considered as one of the major concerns for the design of conventional solid flat slabs and numerous tests have been conducted in different situations to study on shear capacity of slabs constructed by bubble deck system.

The connection of floor to the column is an area of high shear strength especially for the flat plate slab systems (Ricker, Häusler, & Randl, 2017). The applied shear has to be discovered whether it is less than or greater than the shear capacity of the bubble deck by the design engineer. No further check is required if it is less; the spheres around the column should be excluded by the design engineer and then recheck is to be done on the shear in the fresh solid section if it is greater. Shear reinforcement is required if the solid section has a shear resistance lower than the applied (BubbleDeck Voided Flat Slab Solutions, 2008).

2.8.3.1 Approved Research

A solid slab was compared with other two types of bubble deck slabs which all of the three slabs having the same slab thickness, 340mm, had conducted a physical shear tests by Professor Kleinmann at the Eindhoven University of Technology in the Netherlands, along with the A+U Research Institute (Lai, 2010). Lai stated the samples contained secured or loose reinforcement steel girders, either way, were loaded and conducted tests at two dissimilar sites. The imposed load (a) and slab thickness (d) with the ratio a/d, were 2.15 and 3. The investigators determined that bubble deck slab had a shear capacity that fell drastically as compared to a solid slab that configured with the loose girder and shear capacity fell when the distance of the support from the load increased. Table 2.7 shows the summarized results.

Table 2.7 Shear capacity with different types of girder

(In % of solid deck)	**a/d = 2.15**	**a/d = 3.0**
Solid deck	100	100
Bubble deck, secured girders	91	78 (81)
Bubble deck, loose girders	77	

Source: Călin *et al*. (2009)

Lai (2010) reported that Professor M.P. Nielsen who led AEC Consulting Engineers Ltd and the Technical University of Denmark had tested both the punching shear resistance and shear strength. They used a non-typical bubble deck slab with the thickness of 188 mm and ratio of imposed load and slab thickness of 1.4. They found that punching shear was roughly 90% of a solid slab, and that shear strength was 90% of the similar slab.

Lai (2010) also reported another test conducted by Tomas Moerk and John Munk from the Engineering School in Horsens, Denmark. They issued out the paper on "Optimising of Concrete Constructions" on the shear resistance of bubble deck. They conducted an experiment on slabs that contained only the binding wire without any girders with a slab thickness of 130 mm and ratio of a/d was 2.3. The mean shear strength was 76% of a solid slab (Călin *et al*., 2009).

2.8.4 Punching Shear

Punching shear is one of the types of failure that occur in reinforced concrete slabs which are subjected to concentrated loads. Punching shear failure happens at column supports in flat slab structures. This type of failure can bring disaster to the whole structure because it does not show visible signs. Punching shear is a kind of failure which is brittle by controlling the ultimate limit state for reinforced concrete slabs which the intense loads are to be subjected (Shu *et al*, 2017). Flat plate slab systems are a good example of greatly concentrated loads from column to slab as shown in Figure 2.8.

Bubble deck slab design for punching shear section is almost the same as a conventional flat slab (Lai, 2010). The design engineer has to ensure and determine whether the involved shear exceeds or does not exceed the shear capacity value of the bubble deck. Figure 2.9 shows the connection of modified column. The ways to diminish punching shear failure are to use flared column heads or drop panels, expand the column or improve the thickness of the slab (Călin, Gînţu, & Dascălu, 2009).

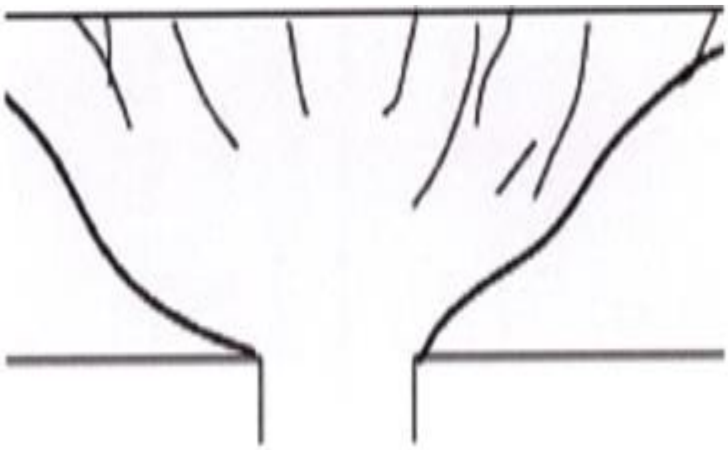

Figure 2.8 Punching shear failure

Source: Lai (2010)

Figure 2.9 Floor to column connection modification

Source: BubbleDeck International (2016)

2.8.4.1 Approved Research

According to Lai (2010), researchers had performed several tests on the behaviour of punching shear of bubble deck slabs. They conducted several tests on slabs with thicknesses of 230mm and 450mm. They discovered that bubble deck slab have comparable and matching crack pattern with a conventional solid flat slab. Besides, a few load cases are performed but no local punching failure happened. The bubble deck slab had a mean exploratory value of shear capacity of 80% to conventional solid flat slab. Figure 2.10 shows the plotted results for the shear capacity (Călin et al., 2009).

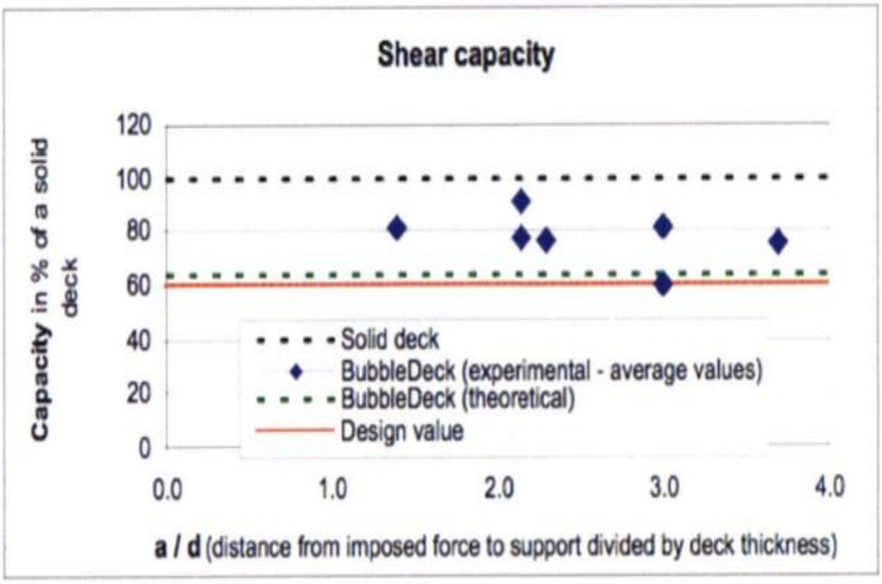

Figure 2.10 Shear capacity

Source: Călin, Gînţu, & Dascălu (2009)

In 1998, Karsten Pfeffer and Martina Schnellenbach-Held from the Institute for Concrete Structures and Materials, Darmstadt University of Technology experimented and performed a study on the behaviour of punching shear of bubble deck. Punching shear capacity test was carried out based on two thicknesses, 240 mm and 450 mm. The slab was fabricate with concrete standards of B25 and B35. The maximum aggregate size was 16 mm. The slab was included with a short column to imitate the practical punching condition. Deflection gauges, strain gauges and extensometers were used to give support to slabs at eight points. The set ups can be seen in Figure 2.11 and Figure 2.12.

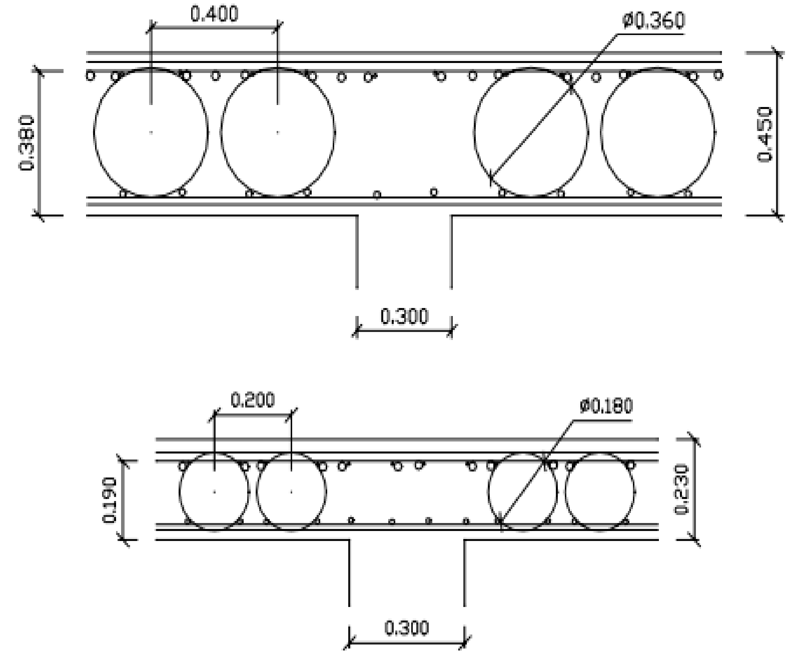

Figure 2.11 Cross-section of the slab specimens
Source: Schnellenbach-Held & Pfeffer (2002).

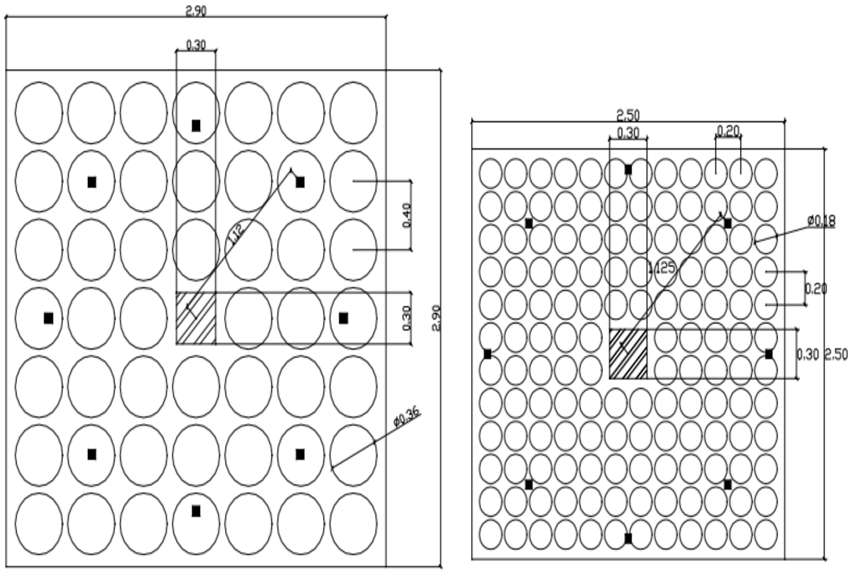

Figure 2.12 Top view of slab specimens
Source: Schnellenbach-Held & Pfeffer (2002).

These experiments had proven that the resistivity against punching shear was below that of conventional solid flat slab although the influence of HDPE plastic spheres on crack pattern across the slab can be considered as insignificant (Schnellenbach-Held & Pfeffer, 2002). When the slab was cut open, the crack pattern showed an angle ranging from 30 to 400 degrees. Figure 2.13 and Figure 2.14 shows the close crack patterns discovered in the tested slabs. In order to further understand the structural mechanics of the bubble deck. The investigators had generated a 3D nonlinear finite element model and followed to the outcomes of the physical examinations and confirmed the behavior of punching shear of bubble deck. They proposed to decrease the area of allowable shear if any HDPE plastic spheres intersect the fixed perimeter so that the HDPE plastic spheres will act as an insignificant role on against the punching shear resistivity. These discoveries were correlated with other researches such that they suggested in mitigating the problem of punching shear in a way that by keeping HDPE plastic spheres out from the shear perimeter. Other studies suggested by excluding the HDPE plastic spheres in the area of column zone preferably than reducing the impact area.

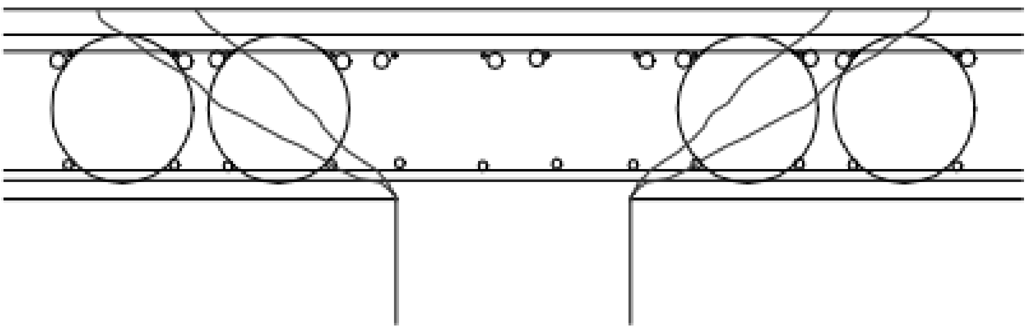

Figure 2.13 Crack pattern in cross-section of slab specimens
Source: Schnellenbach-Held & Pfeffer (2002).

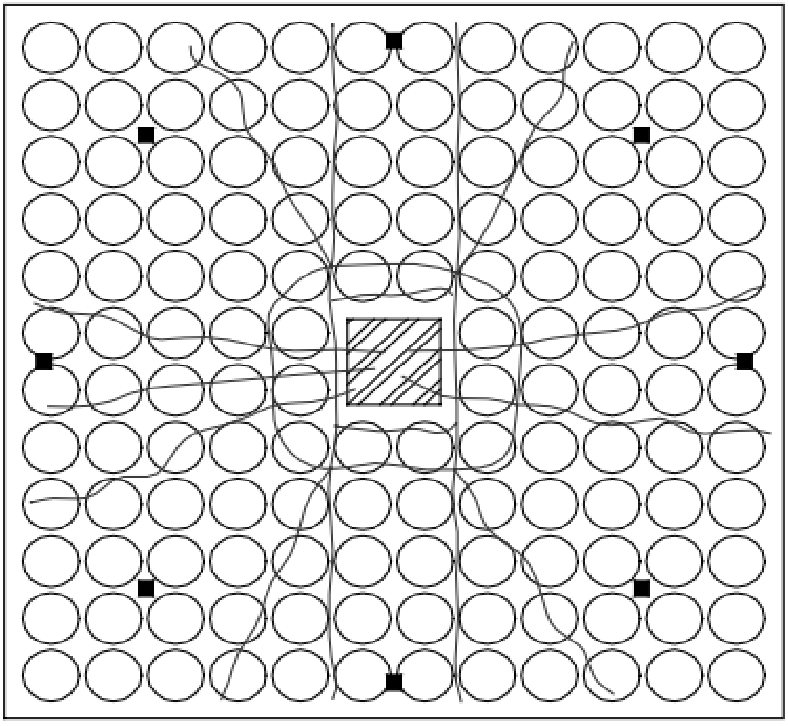

Figure 2.14 Crack pattern in top view of slab specimens
Source: Schnellenbach-Held & Pfeffer (2002).

2.9 Flexural Testing

The main objective of flexure testing is to obtain the flexural modulus and flexural strength of a specimen. The definition of flexural strength if the maximum stress at the outermost fibre on either the compression or tension side of the specimen. Flexural modulus is calculated from the slope of the stress vs. strain deflection curve. These two values can be used to evaluate the sample materials ability to withstand flexure or bending forces.

According to a test conducted by Ukpata and Ephraim in 2012, the arrangement for flexural strength test is shown in Figure 2.15. The automatic universal testing machine was used for this test according to BS1881-118. Beam specimens measuring 500×100×100mm were fabricated and cured in water for a duration of 28 days before flexural testing. Three similar samples were prepared for each mix proportion. The casting was made by filling each mould with freshly mixed concrete in three layers. Each layer was compacted manually using a 25mm diameter steel tamping rod to give 150 strokes on a layer. The hardened beam was placed on the universal testing machine simply supported over a span 3times the beam depth on a pair of supporting rollers. Two additional loading rollers were placed on top the beam. The load was applied without shock at a rate of 200m/s. Flexural strength is calculated and compared among the samples.

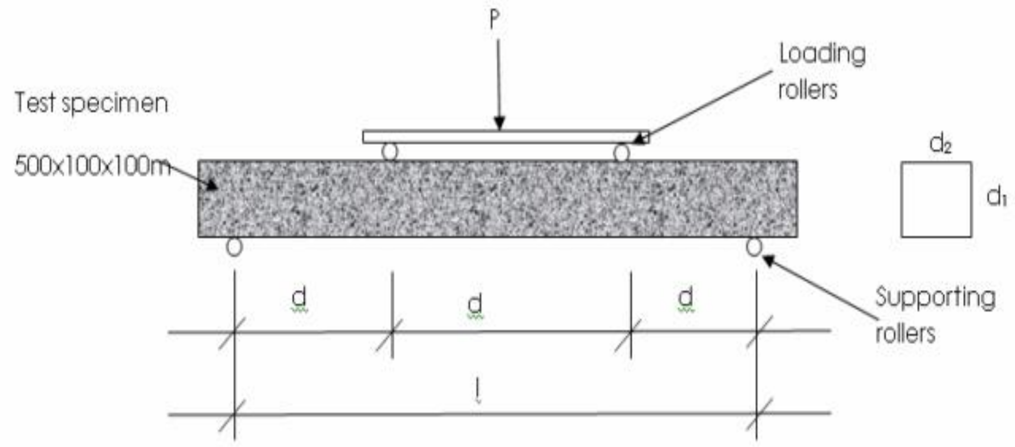

Figure 2.15 Arrangement of four-point loading

Source: Ukpata & Ephraim (2012)

2.10 Modelling of A Bubble Deck Slab Prototype

In advanced engineering, bubble deck slab system consists of a void flat slab which voided parts are replaced by recycled HDPE plastic spheres of bubbles as the idea to remove the concrete that acts as ineffective concrete to improve the structural performance of a slab which also a way to reduce the overall concrete volume. In 2015, Shetkar and Hanche reported that the investigation of behaviours of bubble deck slab in utilizing the HDPE spherical plastic balls and tests were conducted in a laboratory with full-sized structural testing. The plastic spheres of dimensions with a diameter of 240mm and height of 180mm as shown in Figure 2.16 and Figure 2.17.

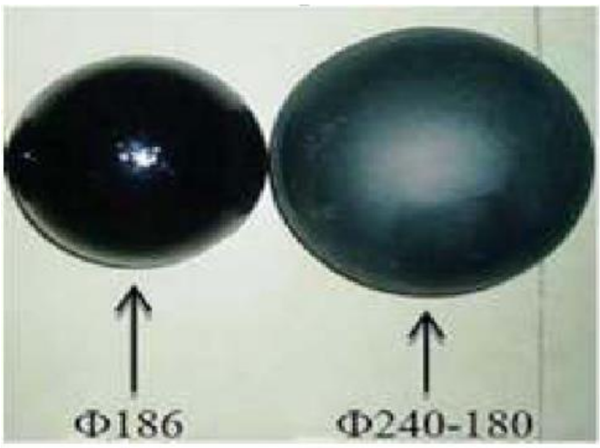

Figure 2.16 Front view

Source: Shetkar & Hanche (2015)

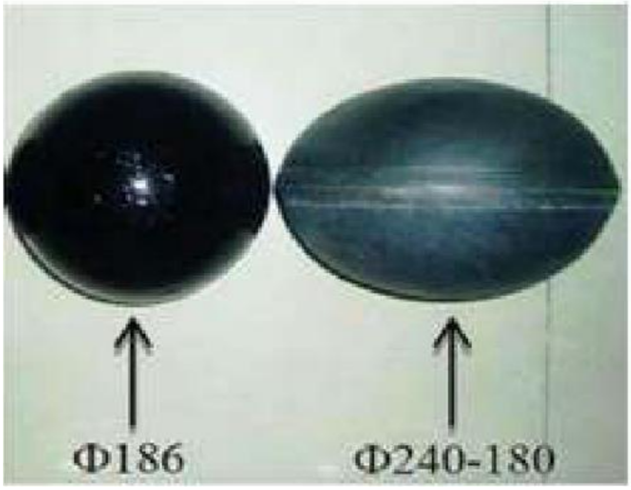

Figure 2.17 Side view

Source: Shetkar & Hanche (2015)

According to Shetkar and Hanche (2015), there were a total of 5 Bubble Deck samples which were A.BD.2, A.BD.3, A.BD.4, B.BD.2 and B.BD.3. All of the specimens were identical in term of dimensions of 1900x800x230 mm. The annotations A and B designated for the concrete strength of B25 and B35 respectively. Table 2.7 outlines the annotation and dimension of Bubble Deck specimens. It was to be highlighted that only the specimen A.BD4 was links supplied while the others did not. Figure 2.18 indicates the sections and plan view of modified Bubble Deck using voided elliptical bubbles. There were a total of 18 elliptical bubbles for a single Bubble Deck specimen. The reinforcement bars at both the layers at the top and bottom was 8mm in diameter and 25mm as the concrete cover.

Table 2.8 Dimension and annotation of Bubble Deck specimens

Slab		**Concrete strength**	**Dimension 1900x800x230mm**		
			BD Dia. 186 (no links)	**BD Dia. 240-180 (no links)**	**BD Dia. 240-180 (have links)**
Annotation	**A**	**B25**	**A.BD.2**	**A.BD.3**	**A.BD.4**
	B	**B35**	**B.BD.2**	**B.BD.3**	

Source: Shafiq Mushfiq *et al* (2017)

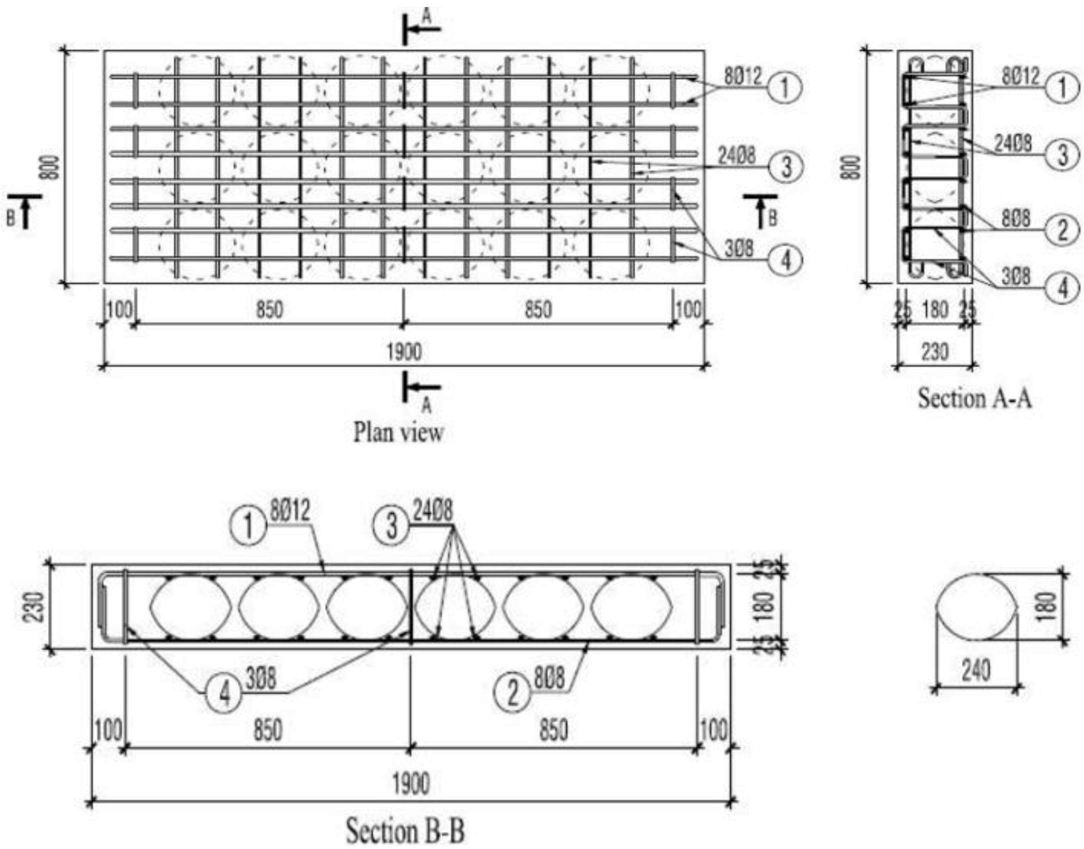

Figure 2.18 Sections and plan view of modified Bubble Deck
Source: Shafiq Mushfiq *et al* (2017)

CHAPTER 3

METHODOLOGY

3.1 Introduction

The objective of this study was to determine the strength of bubble deck slab reinforced with HDPE plastic bubble balls by comparing with the conventional solid slab. This chapter will explain methodology in detailed and demonstrate the flow of works that will be conducted throughout the research to ensure all the objectives were achieved successfully. The flow began with concrete mixing. Then, concrete workability test which was slump test will be carried out to find out the strength of concrete. Structure test such as the tensile test will be carried out on high yield steel and mild yield steel sized 6mm, 8mm and 10mm. Subsequently, destructive tests of which compression test will be conducted on 12 concrete cubes with concrete curing period 3, 7, 14 and 21 days while flexural test will be conducted on 2 slab structures, bubble deck slab and conventional solid slab. Next, results and discussion were done based on the comparisons between the two slab systems. All the experiments were carried out at Concrete Laboratory of Universiti Malaysia Pahang. The standard used as references was Eurocode and ASTM. A flowchart for research methodology process is shown in Figure 3.1.

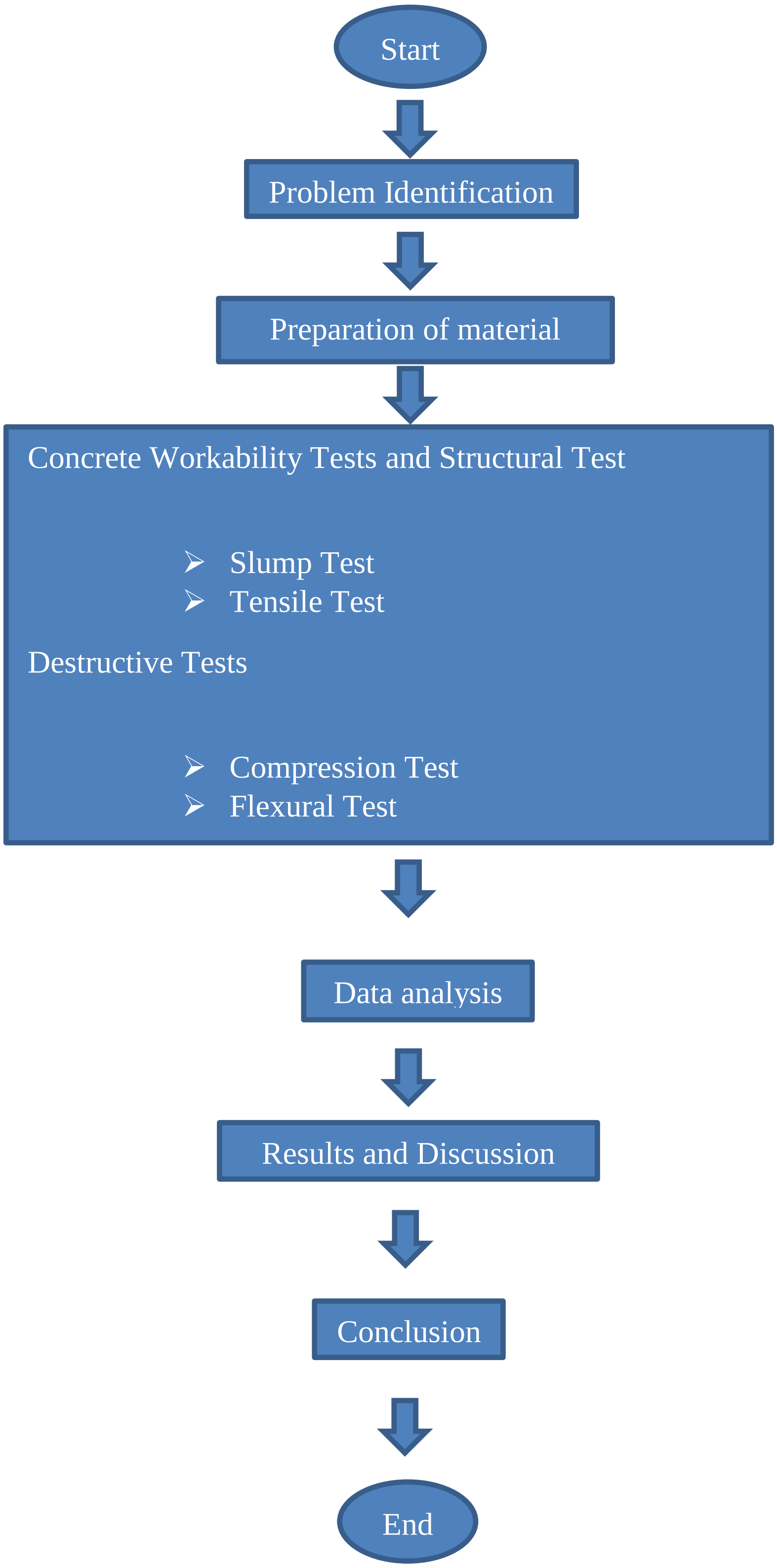

Figure 3.1 Flow chart of research methodology process

Table 3.1 Tests and standards used

Type of test	Tests	Standard used
Concrete workability test	Slump test	BS EN 12350: Part 2 (2009)
Structural test	Tensile test	BS EN 10002-1:2001
Destruction test	Compression test	BS 1881:Part116:1983 ASTM C 39-03
	Flexural test	BS 1881:Part118 ASTM C 78-02

3.2 Materials

The concrete mix design was conforming in accordance to the British Standard: Design of normal concrete, Department of the Environment (DoE), HMSO, 1998.

3.2.1 Cement and aggregates

Type 1 Ordinary Portland Cement (OPC) Grade 30 was used. Fine aggregates were defined by its percentage passing through a 600um sieve. Natural or manufacturing sand was used in concrete mixing. Graded granite with a maximum passing of 20mm was used as the coarse aggregate.

3.2.2 Water-cement ratio

Potable water is used for mixing and curing of concrete. Water-cement ratio should be restricted as per durability as in case of normal concrete and it should preferably be less than 0.55. For the mixing of concrete, the free water per cement ratio specified was known to be 0.48.

3.2.3 Reinforcement bars

There are two meshes of reinforcement bars for the bubble deck slab and conventional solid slab which are connected with girder. The distance between the bars is according to the dimensions and sizes of the HDPE plastic bubbles that are to be used in the slab. Reinforcement mild steel bar yield strength 275 N/mm^2 or higher are used

3.2.4 Hollow bubbles

The plastic spheres or bubbles are made of high density polyethylene materials (HDPE). The bubbles are made with material that are not porous and have chemical resistance with the reinforcement bars and concrete. The bubbles possess great strength and stiffness in supporting the concentrated loads at stages before, during and after pouring of concrete safely. The diameter of the bubble is 225 mm and the distance between the centres of the bubbles is 125 mm. The bubbles are obtained from the Bubble Deck Company are shown in Figure 3.2.

Figure 3.2 HDPE plastic hollow bubbles

Furthermore, the Bubble Deck Company have given a small-scaled bubble deck sample as a reference to aid my project research as shown in Figure 3.3.

Figure 3.3 Small-scaled Bubble Deck sample

3.3 Experimental Setup

The experiment for both bubble deck slab and conventional slab was run in few stages. Each stage explained on the steps of carrying out the works.

3.3.1 Bubble deck slab

Concrete Grade 30 and the voided plastic balls, HDPE with the design methods in accordance with BS EN 13747: 2005.

Stage 1: Prefabricated HDPE plastic bubble balls are ordered and received from the company of the Bubble Deck of Malaysia. The bubbles are made with specific diameter, 225mm. A certain amount of bubbles are obtained and will be assembled in the deck manner on site.

Stage 2: The reinforcement bars lattice is produced by welding both the top and bottom reinforcement together. The bubbles are positioned in place by locking them in between the top and bottom reinforcements. To prevent the escape of bubbles the top and bottom reinforcements are suitably welded together.

Stage 3: The diagonal girders keep the bubbles fixed between the top and bottom reinforcement. Short length diagonal bars are used to connect the top and bottom reinforcements.

Stage 4: The bubble-lattice is lowered into the formwork. Bubble lattice consists of the top and bottom reinforcement along with the bubbles. In filigree elements the bubble lattice is placed into the formwork for preparation of concrete pouring.

Stage 5: Concreting, compacting and surface finishing of the bubble deck slab. Needle vibrators are used for compaction during concreting. And suitable surface vibrators are used for finishing the surface so as to gain a pleasant appearance.

3.3.2 Conventional solid slab

Concrete grade M30 is used and the design specifications are based on conventional design methods in accordance with MS EN 1992-1-1: 2010 of the Malaysian Standard.

Stage 1: The reinforcement bars lattice is produced by welding both the top and bottom reinforcement together.

Stage 2: The diagonal girders fix the distance between the top and bottom reinforcements. Short length diagonal bars are used to connect the top and bottom reinforcements.

Stage 3: The reinforcement bars lattice is lowered into the formwork. The lattice consists of the top and bottom reinforcements.

Stage 4: Concreting, compacting and surface finishing of the bubble deck slab. Needle vibrators are used for compaction during concreting. The suitable surface vibrators are used for finishing the surface so as to gain a pleasant appearance.

3.4 Slump Test

Slump test was carried out to measure the consistency of plastic concrete. First, the internal surface of the mould was ensured to be clean and damp free from superfluous moisture before the start of the test. The mould was placed on a smooth, horizontal, rigid and non-absorbent surface free from vibration as in Figure 3.4.

Figure 3.4 Preparation of slump test

During the process of pouring concrete, the mould was held firmly against the surface below. Three layers of wet concrete were filled, each with almost one third of the height of the mould. Each layer was tamped with 25 strokes of the tamping rod, the strokes being distributed evenly around the cross-section of the layer. After the final layer being tamped, the concrete was levelled off with the top of the mould with a saving and rolling motion of the tamping rod. With the mould still held down, the surface was clean from below any concrete which may have fallen onto it or leaked from the lower edge of the mould.

Next, the mould was removed from the concrete by raising it vertically, slowly and carefully in 5 to 10 seconds, in such a manner as to impact the minimum lateral or torsional movement to the concrete. The entire operation from the start of filling to the removal of the mould was carried out without interruption and completed within 150 seconds. Lastly, as soon as after the mould was removed, the slump was measured to the nearest 5 millimetre using a measuring scale such as ruler to determine the difference between the height of the mould and the highest point of the specimen. Figure 3.5 shows three types of slump: (a) true slump; (b) shear slump; (c) collapse slump.

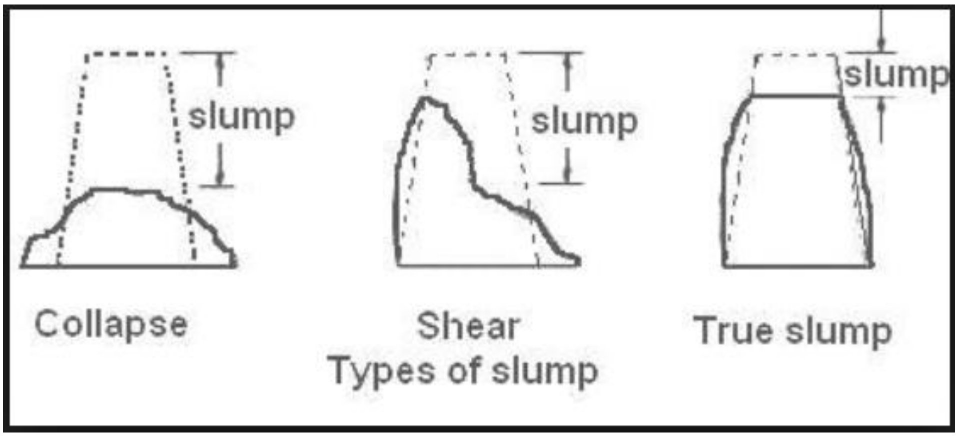

Figure 3.5 Method of measuring slump in slump test

Source: BS EN 12350: Part 2 (2009)

3.5 Tensile Test

A specimen of gauge length, L and cross-sectional area, A is subjected in a testing machine to a gradually increasing load, P until a fracture occurs. Figure 3.6 shows the change in length of a steel bar which was subjected to tensile load. When the load is increased in increments from zero to the point of fracture and stress and strain are computed at each step.

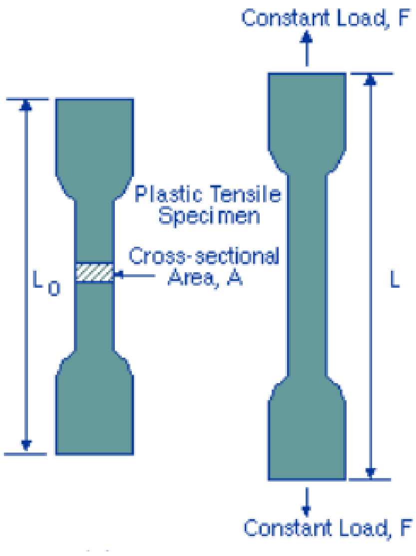

Figure 3.6 Change in length of steel bar subjected to a tensile load

Source:British Standard BS EN 10002-1:2001

Figure 3.7 Universal tensile testing machine

Figure 3.7 shows the universal tensile testing machine that was used for this research. The testing machine has a maximum load of 400kN which is operated by hydraulic and can perform bending and compression test. The stress-strain curve is usually plotted and illustrated as in Figure 3.8. The relationship between the strain and stress was found to be constant in elastic material. For example, the material returns to its original, unloaded dimensions when the load is removed. The determination of ultimate tensile stress is according to the equation below.

$$\text{Ultimate Tensile Stress} = \frac{Maximum\ Load, P}{Initial\ Area, A} \qquad \text{Eq. 3.1}$$

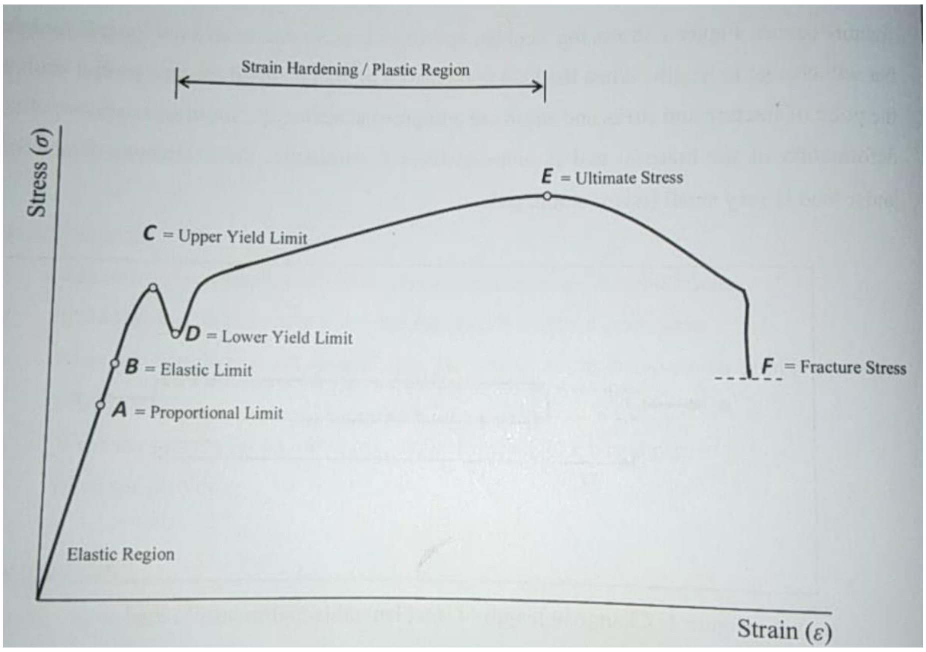

Figure 3.8 Typical curve of stress-strain relationship for mild steel bar

Source: British Standard BS EN 10002-1:2001

The procedures of tensile test went like this. Firstly, the length of steel bar specimen and diameter was measured, d at three different positions then an average diameter of the bar was calculated. Then, the gauge length of 600mm more of less and mark to the bar at the middle was measured. The interval length at every 5d along the bar was marked using the puncher provided. Next, both ends of bar was fixed to the cross-head of UTM machine to grip the bar. The clearance length of bar appeared was call the gauge length. It was important to ensure the bar is parallel with the cross-head of UTM machine. The readings of the load and stroke was recorded until the rod fail. Finally, the bar was removed from the grips and measured the final length and diameter at the breakage point.

3.6 Compression Strength Test

The type of mould used was 150 cubic millimetre. The inner surface of the moulds were wiped with oil for easier removal of moulds after that. Concrete was poured into a total of 12 moulds and was being vibrated as not to have any voids. Then, the moulds were removed and immersed into a water bath for curing after a day.

Three concrete cubes with periods 3 days, 7 days, 14 days and 28 days each with a total of 12 cubes were cured in water. After the particular curing period, the cubes were removed from the water and tested by the machine of compression test. Before the cubes are being tested, the dimension and weight of the specimens were measured. Next, the lower and upper parts of bearing plates as well as the specimens were wiped clean. The specimens were then placed in the middle of the bearing plate and ensured that the upper and lower plain surfaces are positioned correctly. Load at the rate of 140 kg per square centimetre was applied moderately until the concrete cube specimens fail. The compressive strength can be obtained through the division of the failure load by the surface area of the concrete cube. Figure 3.9 shows the specimen being tested in the compression testing machine.

Figure 3.9 Concrete compression test

3.7 Flexural Test

The curing samples were tested once upon removal from water bath. The dimension and weight were measured before testing. Location of supports and loading points on slab surfaces were indicated. The slab samples were then being placed on the testing machine properly and correctly along the axes of the machine as well as perpendicular to the supports. Three-point flexural testing was applied during this study on both Bubble Deck slab and conventional concrete slab. Then, the slab samples were grinded with leather shims contact surface to eliminate the gap in excess of 0.10 millimetre between the specimen and the load applying or support blocks.

The specimens were loaded continuously without shock until they fail. The maximum load carried by the slab samples during testing and the samples cross section at one of the fractured faces were measured. For each dimension of cross section, one measurement at each edge and one at the centre of the cross section were taken. The three measurements were used for each direction to determine the average width and depth to the nearest 1 millimetre. The crack patterns of the failed samples were observed. The rough setup of the sample testing is shown in Figure 3.10.

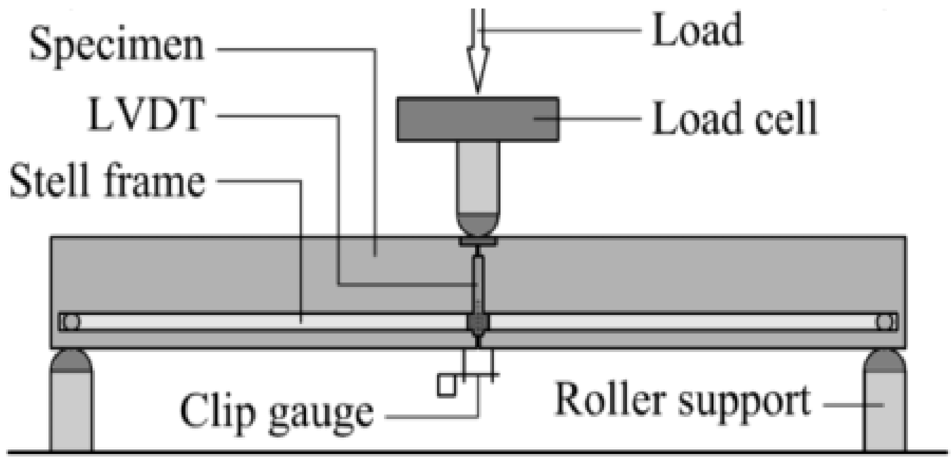

Figure 3.10 Arrangement of three-point loading test piece

Sources: Kozłowski, Kadela, & Kukiełka, 2015

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In this chapter, all the result from the laboratory tests conducted on concrete cubes, high yield and mild steel bars, bubble deck slab and conventional solid slab were obtained. All the materials including formwork, concrete supplied by Pamix Sdn Bhd, steel reinforcement mesh bars and HDPE plastic bubble balls from Bubble Deck Company are thoroughly discussed. The laboratory tests were carried out to identify the performance of bubble deck slab with dimensions 1500mm by 1500mm with thickness of 285mm with comparisons against the conventional solid slab with identical dimensions as bubble deck slab based on flexural strength by three point loading flexural test, type of failure and crack pattern and propagation were observed. Slump test was conducted to determine the consistency and workability of fresh concrete as an indicator to determine whether the concrete was properly mixed. Concrete cube compression test according to the total period of time of concrete curing in water bath was carried out to identify to the strength of concrete provided by Pamix Sdn Bhd. Furthermore, tensile strength test was carried out to determine the tensile strength high yield steel sized 8mm and 10mm while mild yield steel sized 6mm, 8mm and 10mm. All the tests conducted and comparisons made between bubble deck slab and conventional solid slab were discussed in this chapter.

4.2 Slump Test

Slump test is considered as an ordinary method used to experiment on the consistency or in another word workability of fresh concrete. Slump test can be a conductor on construction site or in the laboratory because it is simple. It acts as an indicator of how the fresh concrete behave. Figure 4.1 shows the slump test was done on site.

Figure 4.1 Slump test

The type of slump obtained was a shear slump. Shear slump implies that the concrete mix was not having enough cohesion. Therefore, in consequence, the bleeding and segregation may occur and it can be considered as undesirable for concrete use as it may affect the durability of the concrete structure. In order to improve the matter, a second attempt was made and a true slump was obtained.

4.3 Compression Test

Concrete cube compression strength test indicates the idea which can be a good judgement on the characteristics of the concrete strength. This test alone is enough to show whether the works of concrete mixing was done in a proper way. Some of the factors that can affect the concrete cube compressive strength are cement strength, quality of concrete material, water-cement ratio and quality control during the manufacturing of concrete. Plastic cube moulds of dimensions 150mm x 150mm x 150mm were used for this test. Oil was applied to the inner surface of the moulds before pouring concrete. The moulds were removed after 24 hours and then proceeded with transferring of all the concrete cubes into water for curing process.

Table 4.1 The overall results of compressive strength test

Design number	Age of curing	Cube number	Dimension (mm x mm x mm)	Mass (g)	Compressive strength (N/mm^2)	Failure load (kN)	Average strength (N/mm^2)
1	3	1	150 x 150 x 150	7693.5	11.35	255.4	10.84
	3	2	150 x 150 x 150	7701.8	10.74	241.7	
	3	3	150 x 150 x 150	7569.8	10.44	234.9	
2	7	1	150 x 150 x 150	7716.4	25	562.5	25.54
	7	2	150 x 150 x 150	7620.5	25.18	566.6	
	7	3	150 x 150 x 150	7615.2	26.43	594.7	
3	14	1	150 x 150 x 150	7707.3	30.21	679.7	30.21
	14	2	150 x 150 x 150	7699.1	29.44	662.4	
	14	3	150 x 150 x 150	7588.8	30.98	697.1	
4	28	1	150 x 150 x 150	7599.2	32.26	725.9	31.88
	28	2	150 x 150 x 150	7635.2	30.53	686.9	
	28	3	150 x 150 x 150	7688.6	32.84	738.9	

As the concrete strength increases with time during the period of concrete curing, it is known that for 3 days, 7 days, 14 days and 28 days, the concrete strength can achieve 40%, 65%, 90% and 99% respectively to 12 N/mm^2, 19.5 N/mm^2, 27 N/mm^2 and 29.7 N/mm^2. Based on the results obtained, 7 days, 14 days and 28 days were all obtained a strength of more than the theoretical values except for 3 days which was 1.16 N/mm^2 less than the theoretical value. This happened due to the low consistency of curing period. The cubes were taken out of curing bath and test was conducted on them when the concrete cube was not cured fully 3 days. Figure 4.2 shows the forecast of the concrete compressive strength of the 3 cubes for a total of 56 days.

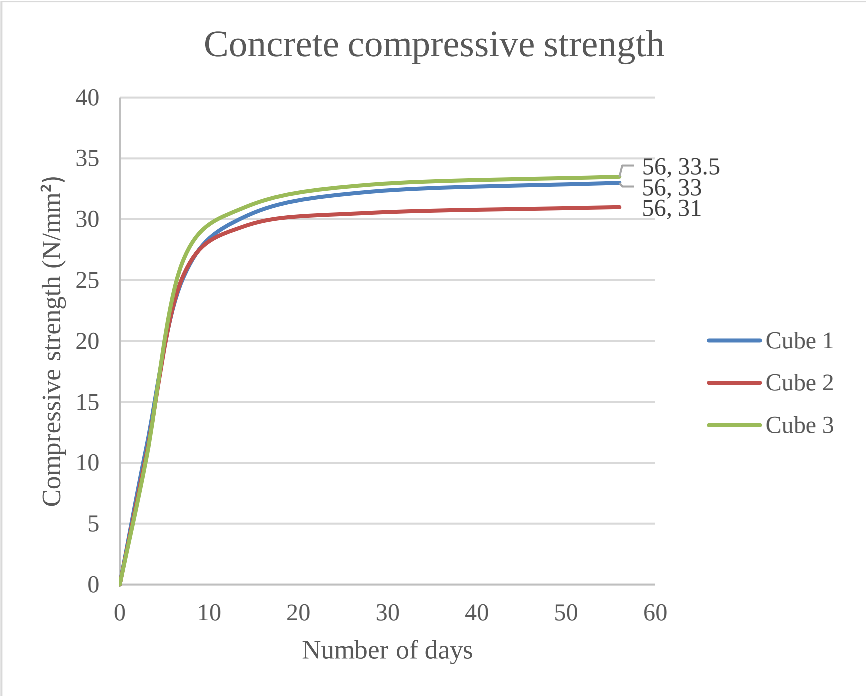

Figure 4.2 A forecast of concrete compressive strength

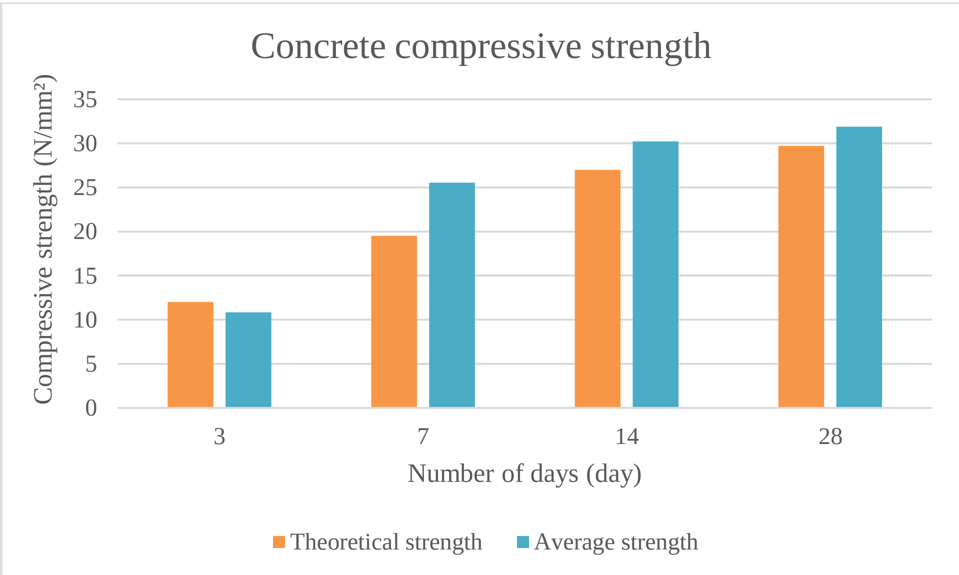

Figure 4.3 Comparison between average strength and theoretical strength

Figure 4.4 Failure of concrete cube specimen

Figure 4.4 above was the aftermath of concrete cube compression test. The crack pattern was well-spread throughout the concrete cube horizontally. In addition, it can be categorised into the satisfactory failure based on the observation on the failure mode.

4.4 Tensile Strength Test

The tensile test is a basic destructive test carried out on steel rod of different sizes and types. This test is comparatively cheap, standardized and simple. It is considered as a test that supplies statistics and data about the ductility of steel, yield strength and tensile strength. Figure 4.5 shows the tensile test was carried out in the concrete laboratory.

Figure 4.5 Tensile test

Based on the Eurocode standard, there were some discrepancies between the experimental and theoretical results that require in-depth and detailed discussion. There were some errors and mistake during conducting of experiment or preparing the specimen. For instance, when deciding to use high yield steel sized 6mm, it was then found out there was no high yield steel sized 6mm available in the laboratory which then mild yield steel sized 6mm was used instead. Thus, the extra tensile test was required to determine the percentage drop in strength of slab samples.

Table 4.2 Tensile tests on several types of steel bar

Sample Reference	Type	Length (mm)	Diameter (mm)	Yield Stress (N/mm^2)	Ultimate Tensile Stress (N/mm^2)	Elongation (mm)
Y10	High yield	612	9.58	543.66	613.61	15.08
Y8	High yield	607	7.75	503.23	576.80	4.36
R10	Mild	408	9.60	360.51	481.66	15.34
R8	Mild	418	7.78	342.03	430.25	12.23
R6	Mild	405	5.77	313.51	403.46	3.59

Table 4.2 shows the overall results of the tensile test on several types and sized of steel bar which was high yield and mild yield steel bar sized 6mm, 8mm and 10mm. There is no result for high yield steel bar sized 6mm due to the unavailable of material in the concrete laboratory. The results indicated that high yield steel bar possessed relatively higher tensile strength than a mild yield steel bar.

Table 4.3 Percentage drop of stress between Y10 and other steel types

Sample Reference	Ultimate Tensile Stress (N/mm^2)	Percentage drop of Stress (%)
Y10	613.61	-
Y8	576.8	6.0
R10	481.66	21.5
R8	430.25	30.1
R6	403.46	34.2

Table 4.3 showed that the percentage drop of stress of Y8 and R10, R8 an R6 compared to Y10 steel bar. It can be concluded that mild yield steel bar R10 possessed relatively low strength even if to compare with high yield steel bar Y8. In this study, steel reinforcement size of R6 was used. In conclusion, R6 had a 34.2% drop of strength compared to Y10.

4.5 Flexural Strength Test

Flexural test evaluates the tensile strength of concrete indirectly. It tests the ability of unreinforced concrete beam or slab to withstand failure in bending.

4.5.1 Three-Point Bending Test

The three-point bending test was carried out to obtain the flexural strength of conventional slab and bubble deck slab. Both the samples were of the size of 1500mm x 1500mm x 285mm. Adequate reinforcement was provided for both of the samples. The detailing of the reinforcement was shown in Figure 4.6 and Figure 4.7. The slab samples were supported by two steel rollers of diameter 3 cm.

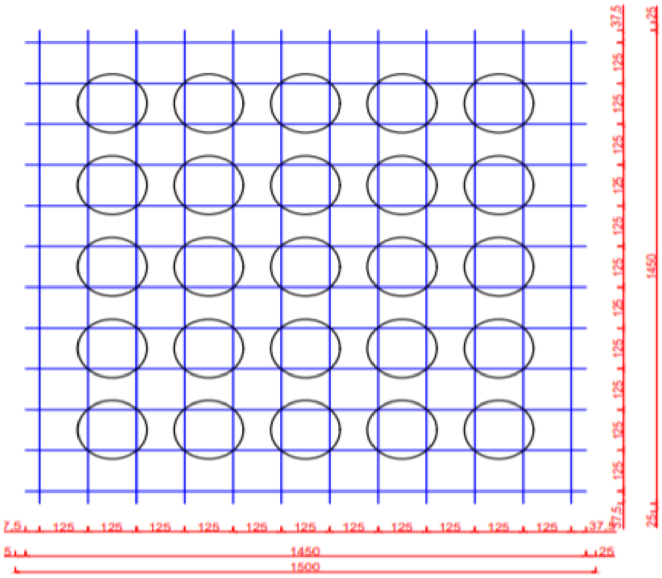

Figure 4.6 Top view of slab specimen

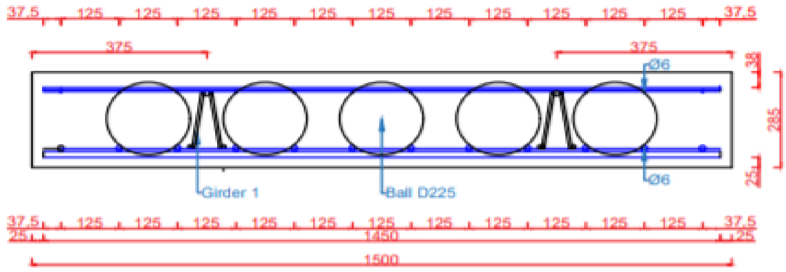

Figure 4.7 Side view of slab specimen

4.5.2 Linear Variable Differential Transformer

The linear variable differential transformer which also called LVDT was used to obtain the deflection of the slabs with the increase of the load. The set-up of LVDT can be seen below. The values of deflections were generated from the computer-aided software which was then transferred for calculation purpose.

Figure 4.8 Set-up of LVDT

4.5.3 Flexural Strength

Fracture initiated at the area of tension at the middle of the span of both slab samples as shown in Figure 4.9. Hence, the flexural strength was calculated according to the equation as shown below

$$R = \frac{PL}{bd^2} \qquad \text{Eq. 4.1}$$

Where:

R = modulus of rupture (N/mm^2 or MPa)

P = maximum load carried by the specimen during testing (N)

L = Span length (mm)

b = average width of specimen at the fracture (mm)

d = average depth of specimen at the fracture (mm)

Figure 4.9 Crack initiated at the middle of slab sample

Table 4.4 Results of the modulus of rupture

Type of slab	P	L	b	d	R
Bubble deck	128.35	1501	1500	287	447.51
Conventional	174.15	1499	1501	286	608.09

Based on the results above, bubble deck slab had an ultimate load of 128.35 kN and shear strength of 64.17 kN while conventional solid slab had an ultimate load of 174.15 kN and shear strength of 87.07 kN. The design shear strength of high yield steel bar sized 6mm was 188.28 kN with a uniform distributed load of 23.21 kN/m. In other words, the percentage drop of steel bar strength sized 6mm between high yield type and mild yield type was 66% for bubble deck slab whilst 54% for the conventional solid slab. In addition, the results also showed that conventional solid slab has a higher modulus of rupture or flexural strength than bubble deck slab.

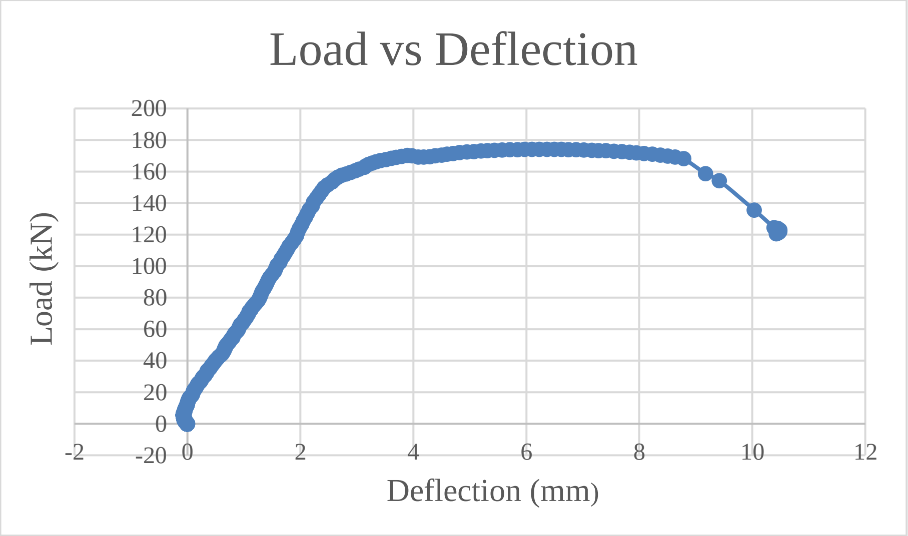

Figure 4.10 Load deflection curve of conventional slab sample

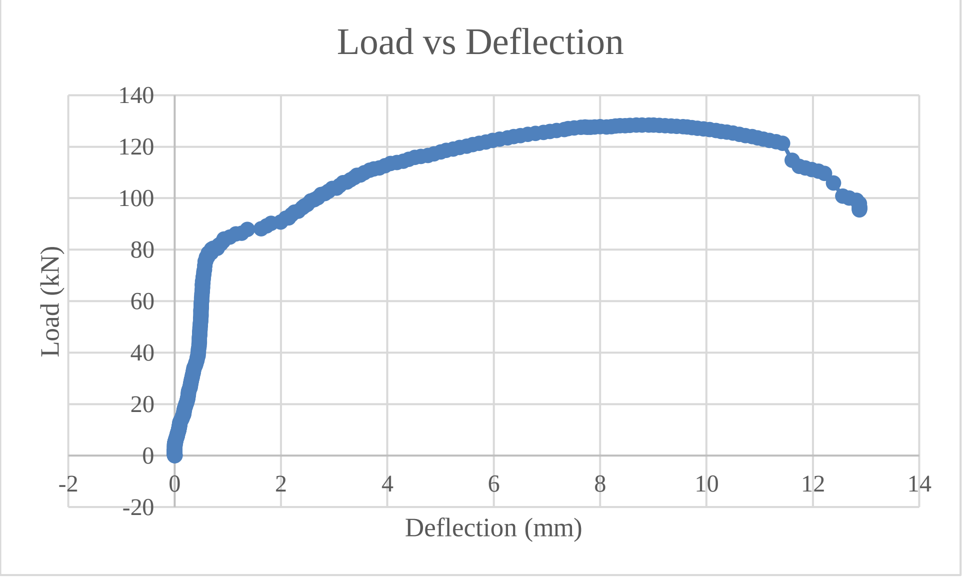

Figure 4.11 Load deflection curve of bubble deck slab sample

Based on Figure 4.10 and Figure 4.11, the results clearly showed that the maximum load achieved in conventional solid slab was higher than bubble deck slab. Figure 4.12 showed the combination of the load against deflection curve for conventional solid slab and bubble deck slab. From the results above, it is clear that bubble deck slab has higher deflection values than conventional slab which means bubble deck slab has higher elasticity compared to the conventional solid slab. In addition, the percentage discrepancy of load for both bubble deck slab and conventional slab are 49% and 31% respectively.

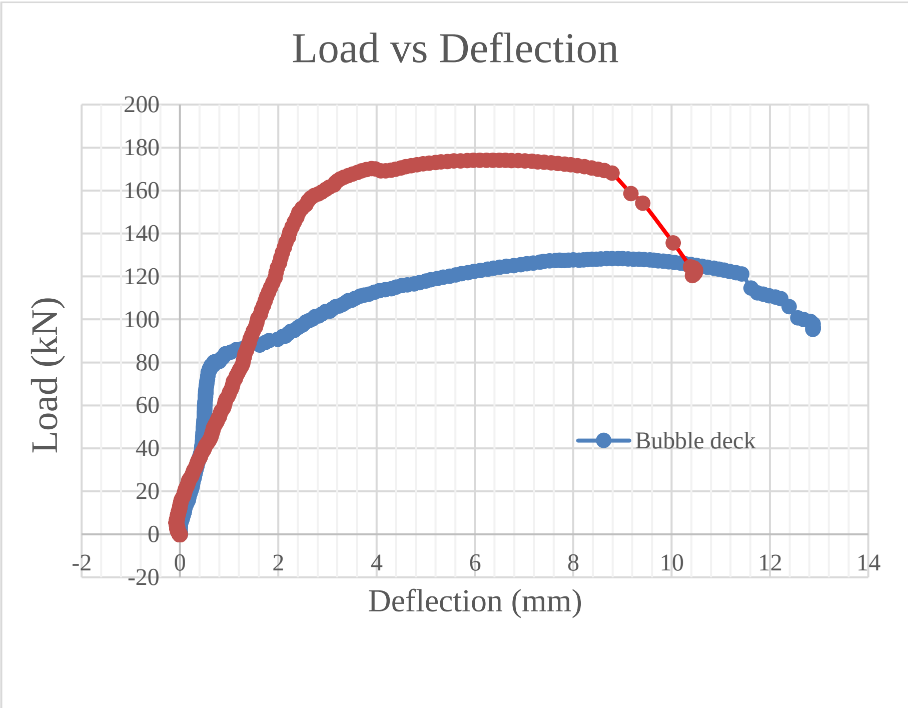

Figure 4.12 Combination of load vs deflection curves of both slab samples

4.5.4 Crack Pattern and Propagation

Figure 4.13, Figure 4.14 showed the crack patterns of the conventional solid slab and Figure 4.15 showed the crack patterns of bubble deck slab after subjected to a static load. The shape of cracks was uneven but the cracks appeared at the tensile surface propagated towards the compression surface. The conditions at supports influenced the shape of the cracks. Based on the observation, the location of the crack was not at the centre of the slab but it was still acceptable because it only located between 2-4 mm from the centre.

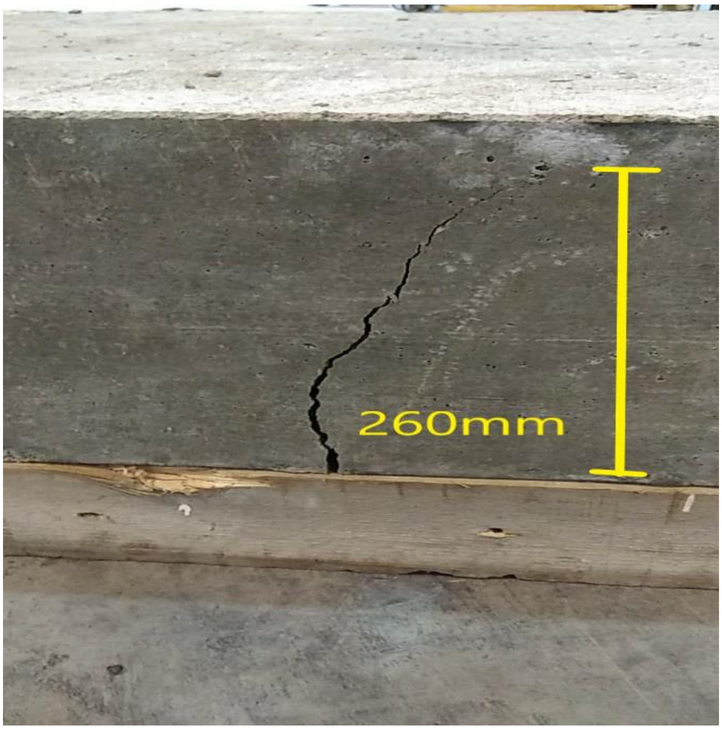

Figure 4.13 Crack pattern in conventional solid slab at left end

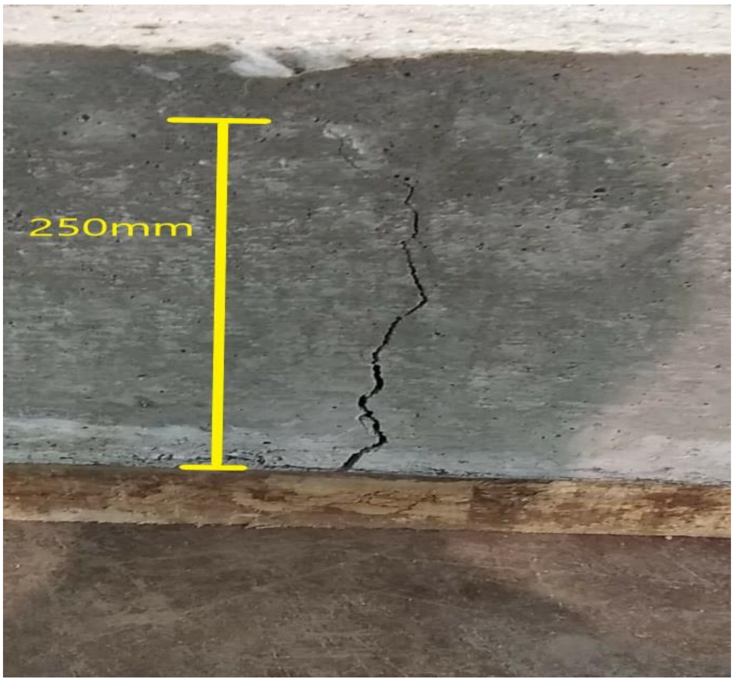

Figure 4.14 Crack pattern in conventional solid slab at right end

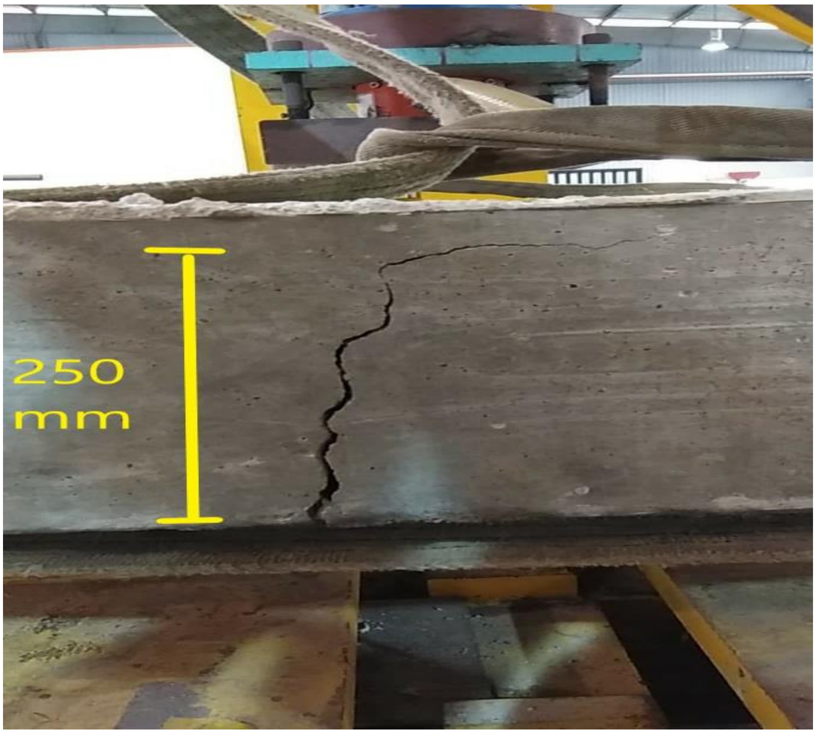

Figure 4.15 Crack pattern in bubble deck slab

CHAPTER 5

CONCLUSION

5.1 Introduction

The main focus of this research was on the determination of the performance of bubble deck slab. Several tests were conducted along the way to test the strength of bubble deck slab with comparisons made with the conventional solid slab. All the meticulous works had been a success in satisfying the three main objectives of this research project. Chapter 5 will include the conclusion, contribution of several parties and lastly the recommendations.

5.2 Conclusion

The main focus of this research project was to identify the performance of bubble deck slab based on the several tests that had been conducted in term of the flexural strength of the slab by comparing with conventional solid slab. Based on the several tests that had been conducted, several conclusions can be made:

1. Based on British Standard, slump test was carried out before the casting of concrete. The type of slump obtained was a shear slump. Shear slump implies that the concrete mix was not having enough cohesion. Consequently, bleeding and segregation may occur and it can be considered as undesirable for concrete use as it may affect the durability of the concrete structure. In order to improve the matter, a second attempt was made and a true slump was obtained.

2. Based on British Standard and ASTM, compression test was conducted on 12 concrete cubes of dimensions 150 cubic millimetres. The results acquired showed that 7 days, 14 days and 28 days achieved a strength of more than the theoretical values except for 3 days which was 1.16 N/mm^2 less than the theoretical value. This happened due to the low consistency of curing period. The cubes were taken out of curing bath and test was conducted on them when the concrete cube was not cured fully 3 days. The results had also proved that it consisted correct and accurate forecast for concrete compressive strength. Moreover, the results of concrete cube compression test showed that the crack pattern was well-spread throughout the concrete cube horizontally which it can be categorised into the satisfactory failure based on the observation on the mode of failure.

3. For the tensile test, threaded steel reinforcement bar possessed higher grip strength resulted in having high tensile strength compared to the non-threaded steel reinforcement bar. The high yield reinforcement steel bar is relatively stronger than mild yield reinforcement steel bar. There is no result for high yield steel bar sized 6mm due to the unavailable of material in the concrete laboratory. As a result, mild yield steel bar sized 6mm was used as a reinforcement for both the slab samples. Therefore, this additional tensile test was necessary and essential in determining the percentage difference of strength by comparing with the design values of high yield steel bar. In this study, steel reinforcement size of R6 was used. In conclusion, R6 had a 34.2% drop of strength compared to Y10.

4. The flexural tensile test was carried out without difficulties. From the results obtained, the percentage drop of shear strength was 66% for bubble deck slab whilst 54% for a conventional solid slab with comparison with design shear strength of 188.28 kN. The modulus of rupture of bubble deck slab was 447.51 N/mm^2 which was lower than the conventional slab, 608.09 MPa. However, there was this problem of delay of flexural test on slab samples. For instance, the machine was delayed for more than 4 months. Hence, the expected flexural testing on slab samples after curing period of 28 days was not able to achieve.

Slab samples were tested after 70 days of curing. Therefore, the strength obtained was not accurate for future design and evaluation.

5.3 Recommendation

The results of the laboratory experiment shown that conventional solid slab had higher flexural strength compared to bubble deck slab but bubble deck gave a positive improvement in term of elasticity. Some suggestions for the future investigation were given below:

1. In this study, by referring to the previous work, non-threaded mild yield reinforcement steel bar meshes were used. This study could be further improved in the future by using threaded high yield reinforcement steel bar meshes which could greatly increase the surface area of contact between reinforcement bar meshes by the interlocking properties with concrete and by comparing the strength of slab samples by applying Flexural Tensile Test.

2. A 225mm thick HDPE plastic bubble balls and 1500mm x 1500mm length and width of slab samples were used. For further study, it would be better if the smaller thickness of HDPE and dimensions of slab samples were used for easier execution and handling of works. Thus, works can be done easier and results obtained would be more accurate.

3. Shear reinforcement was not provided for the slab samples in this project. The study could be further improved by providing shear reinforcement to prevent shear cracks.

4. It is important to ensure all laboratory machines are in optimal condition. Thus, the design of sample dimensions and reinforcement steel size are curtained during the planning stage. As a result, no delay for structural testing would emerge for testing and results obtained would be more accurate for further design calculations and evaluations.

5. Utilize strain gauges during the flexural tensile testing to determine the principle strain of the slab samples.

6. Bar meshes should be used. If there is no size available for the particular steel bar size, do not weld the mesh due to the inconsistency of shapes and length.

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APPENDIX A
SAMPLE APPENDIX 1

TENSILE TEST RESULT

Sample : High Yield and Mild Yield Steel Bar

Test Method : BS EN 10002-1:2001

Tested date : 8 May 2018

No	Size (mm)	Sample Reference	Type (M.S/H.T)	Length (mm)	Diameter (mm) Average	Weight (g)	Gauge Length Before Test, L0 (mm)	Gauge Length After Test, L1 (mm)	Peak (kN)	Yield Load (kN)
1	10	T10	H.T	612	9.58	363.58	50	65.08	46.438	41.031
2	10	R10	M.S	408	9.6	248.57	50	65.34	39.745	28.004
3	8	T8	H.T	607	7.75	236.52	40	44.36	30.832	29.62
4	8	R8	M.S	418	7.87	165.57	40	52.23	23.274	16.754
5	6	R6	M.S	405	5.77	86.01	30	33.59	13.962	8.752